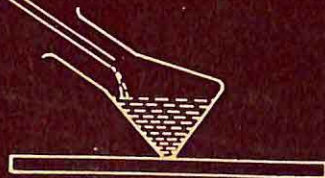
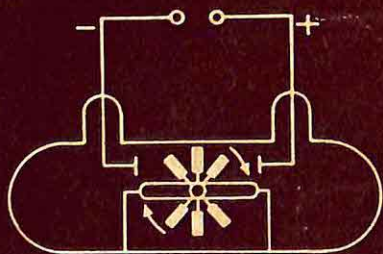
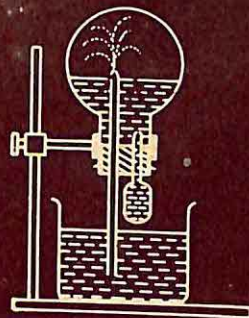
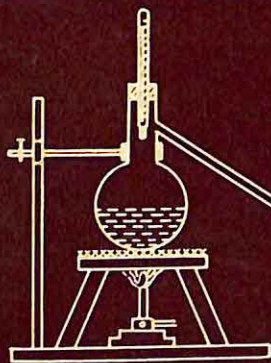


Revision in CHEMISTRY

1

D P GOEL
S P MITTAL



ORIENT LONGMAN

REVISION IN CHEMISTRY

Revision in CHEMISTRY

Volume 1

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Preface

This book is aimed primarily at the students of classes 9 and 10 offering the Science Course A of the All India Secondary School Examination. It has been written with the dual purpose of providing the subject matter to the students in a crisp form, as well as aiding them in preparing for the examinations.

The subject matter is presented in a question-answer format in clear and simple language. In each chapter important definitions and laws have been given at the beginning, and the physical and chemical properties of elements provided in a tabular format, to serve as a ready reckoner. As a further aid to preparation for the examination, exercises have been provided at the end of each chapter. SI units have been used throughout.

This is the first of the two volumes, covering the class 9 syllabus.

The authors would welcome comments and suggestions from students and teachers who use the book.

August 1982

D.P. GOEL
S.P. MITTAL

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Syllabus for Classes IX and X

(All India Secondary School Examination, Chemistry, Course A)

1. Importance of Chemistry in Everyday Life (non-evaluative).

2. Elements, Compounds and Mixtures

Elements, compounds and mixtures, types of mixtures and their separation.

3. Chemical Communication

Symbols of elements, chemical equations and simple calculations based on chemical equations.

4. Behaviour of Gases

Introduction, volume-pressure, volume-temperature and pressure-volume-temperature relationships for a gas (combined gas law), Kelvin temperature scale, Gay-Lussac's law, Avogadro's law, mole concept, gram molecular volume of a gas at standard temperature and pressure. Simple calculations based on applications of gas laws and the mole concept.

5. Structure of the Atom

Electrical nature of matter, electric discharge through gases under reduced pressure, cathode rays and positive rays, evidence for the existence of nucleus; protons, neutrons and atomic number, nuclear model of an atom, distribution of electrons in shells (K,L,M,N), electronic configurations of first 20 chemical elements, isotopes, valence electrons.

6. Chemical Bonding

Inertness of noble gases, electrovalent and covalent bonds, properties of electrovalent and covalent compounds, formation of some elementary molecules, e.g. H_2 , O_2 , N_2 , CH_4 , CCl_4 , and C_2H_2 with special reference to single, double and triple bonds, polarity in HCl molecule.

7. Periodic Classification of Elements

Periodic classification (Mention of Mendeleev's work), modern basis of periodic classification (Periodic law), long form of periodic table, idea of groups and periods and their general characteristics.

8. The Halogens

Occurrence in nature, general methods for the preparation of halogens, laboratory preparation and properties of chlorine, relative reactivity of halogens (displacement reactions), detection of halogens (except fluorine), uses of halogens. Hydrogen chloride and hydrochloric acid, preparation in laboratory, properties and uses. Preparation and uses of bleaching powder.

9. Oxygen and Sulphur

Occurrence of oxygen and sulphur, atmospheric oxygen, use of oxygen in burning, formation of oxides of metals and nonmetals, rusting, uses of oxygen, extraction of sulphur (Frasch method), effect of heat on sulphur, preparation of monoclinic and plastic sulphur, preparation and properties of hydrogen sulphide, oxides of sulphur—sulphur dioxide, its laboratory preparation and properties; sulphur trioxide—its preparation and use in the manufacture of sulphuric acid by contact process.

10. Nitrogen and Phosphorus

Preparation of nitrogen in the laboratory, physical properties of nitrogen, interaction of nitrogen with hydrogen, halogens and oxygen. Ammonia—its laboratory preparation and properties, uses of ammonia and its compounds. Oxides of nitrogen—simple properties of nitric oxide and nitrogen dioxide; preparation, properties and uses of nitric acid, uses of nitrogen and its compounds—fixation of atmospheric nitrogen and nitrogen cycle; detection of nitrate ion in salts.

Occurrence of phosphorus in nature, allotropes of phosphorus, interaction of phosphorus with oxygen, chlorine, acids and alkalies, uses of phosphorus and its compounds, preparation and uses of superphosphate, detection of phosphate ion in salts.

11. Metals and Metallurgical Processes

Common characteristics of metals, simple chemical properties of Na, Ca, Mg, Al, Zn, Fe, Pb and Cu (reactions with air, hydrogen, halogens, sulphur, water and acids), industrial preparation of sodium hydroxide and sodium carbonate. Occurrence of metals in nature, extraction of iron, aluminium, copper and zinc from their ores (outlines only), simple alloys of magnesium, aluminium, zinc, copper, iron and lead.

12. Hydrogen and Water

Hydrogen—occurrence and importance, displacement of hydrogen from water and acids by metals; sources of water, hard and soft water, removal of temporary and permanent hardness of water, purification of water for drinking.

13. Solutions and Electrolytic Dissociation

Solutions, colloids and suspensions; solubility, solute and solvent, use of water as a solvent; exothermic and endothermic changes during dissolution of substances in water, concentration of solutions.

Electric conductivity of solutions, electrolysis, electrolytes and non-electrolytes, pH scale, dissociation of

acids, bases and salts in water, some uses of electrolysis (electroplating, electrorefining and electrotyping).

14. Types of Chemical Changes and Rates of Reactions

Types of chemical changes (combination, decomposition, substitution, double decomposition, reversible and irreversible reaction, oxidation and reduction, oxidising and reducing agents, exothermic and endothermic reactions). Factors affecting reaction rates—nature and state of reactants, concentration temperature, catalyst. Chemical equilibrium and Le Chatelier's principle.

15. Carbon

Occurrence of carbon in nature, structure of carbon—tetravalency, allotropic modifications of carbon properties and uses of diamond and graphite. Formation of carbon monoxide and its uses, carbon dioxide—its laboratory preparation, properties and uses.

16. Fuels

Solid, liquid and gaseous fuels, energy value of fuels, combustion, conditions necessary for combustion. Fire extinguishers.

17. Compounds of Carbon (Organic Chemistry)

Hydrocarbons—Introduction to saturated and unsaturated, aliphatic and aromatic hydrocarbons, homologous series, some physical and chemical properties of hydrocarbons, test for some reactive functions (alcohol, aldehyde and carboxylic acid) in organic compounds. Classification of organic compounds and their nomenclature. Elementary study of petroleum and petrochemicals.

Note : 1-10 are covered in *Revision in Chemistry*, Vol. 1. 11-17 are covered in *Revision in Chemistry*, Vol. 2.

UNIT 1

Importance of Chemistry in Everyday Life

This unit is concerned with the impact of chemistry on our day-to-day life. Chemistry is one of the vital areas of science helping in the effort of providing us with a better life. All our activities are affected by chemistry. Plastics, fuels, cosmetics, fertilizers, medicines, metals and alloys, textiles, etc. are the results of chemistry. They have helped in making our life comfortable. So much so that now we cannot even imagine a life without the boons of chemistry.

Science is a study of the nature of matter. In the various branches of science we investigate :

- (i) What materials exist in nature.
- (ii) What happens to these materials.

Physical sciences, e.g. physics, chemistry, etc. deal with the investigation of the inanimate world, while the biological sciences, e.g. botany, zoology, etc. deal with the study of living things.

Chemistry is the study of the nature of matter and the changes which matter undergoes. Chemistry investigates :

1. The composition of matter.
2. The properties of materials.
3. The reason for chemical behaviour.

APPLICATIONS OF CHEMISTRY

(i) *Food resources* : The productive capacity of land has been increased several-fold by the use of chemical fertilizers and insecticides. Chemical fertilizers, like natural fertilizers, supply vital elements such as nitrogen, phosphorus and potassium. Their need was felt when the yield from agricultural land fell short of the requirement for the ever increasing population.

Use of certain chemicals (insecticides) for killing rats, insects, worms, etc. has helped in increasing the food resources enormously.

Selection of soil suitable for a particular crop has been facilitated with the knowledge of chemistry. Thus, any type of deficiency in the soil can be overcome by adding certain chemicals and fertilizers.

Knowledge of chemistry helps us in planning a balanced diet. It also helps us in checking the quality of food material.

(ii) *Health and medicine* : Perhaps the biggest impact of chemistry on mankind has been in the understanding, prevention and cure of diseases. This has enabled man to live a longer and healthier life. Anaesthetics and analgesics relieve pain and make modern surgery possible. Antiseptics

help in healing cuts and wounds and prevent the spreading of diseases. Antipyretics help to lower down the body temperature. Tranquilizers help to reduce anxiety in patients by acting on the central nervous system. Sulpha drugs and antibiotics destroy harmful bacteria to cure dangerous diseases. These are all the products of chemistry.

(iii) *Communication and entertainment* : Both physical and intellectual communication play an important role in our lives. Physical communication is the ability to travel and to move materials about. Chemistry has helped in providing the materials for building the machinery for travelling. It also provides power to make them work. Power for cars, trains, satellites, aeroplanes, ships, etc. is obtained from cells and fuel, both of which employ chemicals and convert chemical energy to useful work.

Intellectual communication, i.e. the ability to communicate in speech and writing, is of immense importance in the world of today. Information is communicated by writing on paper with ink. Both of these are produced by chemical processes.

Wireless and telephones have revolutionized our society. Many of the parts used in them require the aid of chemistry.

Films provide a means of entertainment and education to the masses. Chemical processes are used to manufacture raw films and to process the exposed films. Radios, transistors, television, tape recorders, etc. are a constant source of education and entertainment. Research and development in the chemistry of materials has been largely responsible for manufacturing the electronic devices which make them work.

(iv) *Fuels and energy* : At one time wood was perhaps the only fuel available to mankind. Now fossil fuels, i.e. coal, oil and natural gas are the major fuels and sources of energy. Chemistry has helped immensely in making these available to mankind.

With the decreasing stock of fossil fuels scientists have started counting upon the energy

confined within the atoms—nuclear fission or nuclear fusion. Nuclear fission is now being used in nuclear power stations to produce electricity all over the world. Plutonium produced from uranium-238 is generally employed as nuclear fuel.

Chemistry has also been helpful in improving the quality of various fuels and their calorific values. Coal, for example, gives out too much of smoke. It can be converted by a chemical process into coke which gives out comparatively much less smoke and burns more efficiently.

Natural gas is an important fuel. It is used in manufacturing many chemicals. Domestic gas (LPG—liquefied paraffin gas), an important modern fuel, has made cooking very easy. These days gas from waste material, *gobar gas*, is also being made available, again through research and development in chemistry.

The production of all these fuels involve chemistry in one way or the other.

(v) *Fibres* : Synthetic chemistry has given fibres like nylon, terylene, rayon, polyacrylic to mankind. These man-made fibres rival, and in some respects are superior, to the natural fibres like cotton, silk and wool. They are longer lasting, crease resistant and quick drying.

Clothes made out of a mixture of synthetic and natural fibres have certain advantages and are now available. Terecot, terewool and teresilk are examples of these. Chemistry also helps in converting cotton waste and pulp (from trees) to artificial silk.

(vi) *Population control*: Population explosion is one of the major threats to the present-day civilization. Increasing population is putting strains on the air, the water, and on the mineral, energy and food resources of this planet. Chemists have to do a lot to prevent this massive population explosion. Education of parents and chemical methods have been helpful in controlling the size of families.

(vii) *Other amenities* : Chemicals like chlorine, bleaching powder, potassium permanganate and

alums are used to kill harmful germs present in water supplied in towns.

Soaps and detergents are gifts of chemistry used in washing and cleaning. Many chemicals are used in cleaning lavatories and making them germ free.

Town refuse and garbage can be put to use with the help of chemicals. Industrial wastes are also converted into useful products by various chemical processes. Poisonous industrial wastes

and gases such as sulphur dioxide, nitrogen oxides and carbon monoxide given out by chimneys of factories are the most dangerous pollutants of the atmosphere. Chemistry, however, has helped by developing processes to make chemical waste free of poisonous substances which pollute air and water. Chemistry, thus helps in providing a clean and healthy environment.

UNIT 2

Elements, Compounds and Mixtures

D.2.1 Matter : Anything that occupies space and has weight.

D.2.2 Substance : Any variety of matter of recognizably definite composition and specific properties.

D.2.3 Atom : The smallest particle of an element which can take part in a chemical reaction.

D.2.4 Element : A substance composed of only one type of atoms.

D.2.5 Compound : A pure substance composed of elements chemically combined in fixed proportions.

D.2.6 Mixture : The product obtained when two or more substances, that do not combine chemically, are mixed in any ratio.

D.2.7 Heterogeneous mixture : A mixture with many phases; usually separable by mechanical means.

D.2.8 Homogeneous mixture : A uniform mixture having the same specific properties in all portions.

NOTE : The components of a mixture can be separated by various methods. These are sedimentation and decantation, filtration, evaporation, sublimation and distillation.

D.2.9 Metals : Elements that are good conductors of heat and electricity, are ductile, malleable and have a lustrous appearance.

D.2.10 Non-metals : Elements that are insulators, non-ductile, and non-malleable.

Q.2.1 Define and explain : (a) Substance (b) Element (c) Compound (d) Mixture.

Answer: (a) *Substance* : We see a number of things around us, e.g. wood, metals, water, etc. We do not see air but feel its presence. All these things occupy space and have weight. Anything which occupies space and has weight is called matter.

A substance is any variety of matter of recognizably definite composition and specific properties. Thus, a chair is made of wood; chair is matter and wood is substance.

(b) *Element* : If a substance is composed of only one type of atoms, it is known as an element. Sulphur, silver, mercury, oxygen are examples of elements.

There are 105 elements known at present.

(c) *Compound* : Most pure substances can be decomposed into two or more substances by a treatment that causes a chemical change. For example, water can be decomposed into hydrogen and oxygen by passing an electric current through water (Fig. 2.1). Thus water is a compound.

A compound is a substance composed of elements present in a definite and fixed propor-

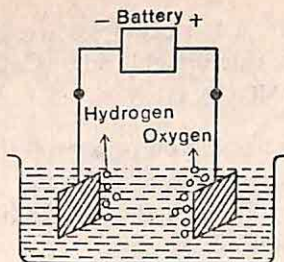


FIG. 2.1 Decomposition of water by an electric current.

tion by mass. For example, carbon dioxide (CO_2), limestone (CaCO_3), benzene (C_6H_6).

(d) *Mixture* : A mixture is obtained by mixing two or more substances in any proportion, with no chemical reaction between them. For example, air is a mixture of many gases, milk is a mixture of water, protein, fats and carbohydrates. Iron and sulphur when mixed form a mixture. Gun powder is a mixture of sulphur, charcoal and nitre.

Q.2.2 Identify each of the following as mixture, compound or element : (i) copper (ii) common salt (iii) brass (iv) sugar (v) air (vi) water (vii) milk (viii) tin (ix) glass (x) silver (xi) marble (xii) paint (xiii) blue vitriol (xiv) gold (xv) sea-water.

Answer

Mixture	Compound	Element
brass	common salt	copper
air	sugar	tin
milk	water	silver
glass	marble	gold
paint	blue vitriol	
sea-water		

Q.2.3 What are heterogeneous and homogeneous mixtures?

Answer : A mixture is a random collection of two or more substances in no fixed ratio. Mixtures are broadly divided into two categories: *heterogeneous* and *homogeneous*.

Heterogeneous mixture : On mixing iron with sulphur a mixture is obtained. In this mixture

the composition of iron or sulphur is not the same throughout. It is a heterogeneous mixture. Using a magnifying glass, the particles of sulphur and iron can be seen lying side by side. The constituents of this mixture can be separated by simple methods.

Homogeneous mixture : In a homogeneous mixture the composition of its components is same throughout. A homogeneous mixture is called a solution. A homogeneous mixture is obtained, for e.g. by dissolving sugar in water.

Q.2.4 Classify each of the following as being heterogeneous or homogeneous: (i) sugar and sand (ii) air (iii) brass (iv) water and benzene (v) water and alcohol (vi) milk (vii) marble and sand (viii) NaCl and KNO_3 .

Answer

Heterogeneous	Homogeneous
sugar and sand	air
water and benzene	brass
marble and sand	water and alcohol
NaCl and KNO_3	milk

Q.2.5 What are the various types of elements? Give examples in each case.

Answer: Elements are classified as metals and non-metals. About one fourth of the known elements are non-metals.

Metals: A metallic element is one whose atoms have the tendency to lose electrons from their valence shells. Common examples of metals are: gold, copper, silver, tin, aluminium, iron, zinc, cobalt and nickel. Metals are solids at room temperature with the exception of mercury and gallium which are liquids. Some characteristic properties of metals are—lustrous appearance, ability to conduct electricity and heat, ductility and malleability.

Non-metals: Non-metals generally exist as powders or gases with the exception of bromine which is liquid under normal conditions. The non-metals generally are not lustrous, and are poor conductors of electricity and heat. They are not malleable and ductile. Non-metals have

lower melting point than metals. Carbon, sulphur, phosphorus are solid non-metals and oxygen, nitrogen, fluorine, chlorine, helium, neon are gaseous non-metals.

Q.2.6 Which of the following are metals and which are non-metals? Hydrogen, aluminium, chlorine, xenon, sulphur, potassium, mercury, iodine, carbon, lithium, lead, tungsten, platinum and oxygen.

Answer:

Metals	Non-metals
aluminium	hydrogen
potassium	chlorine
mercury	xenon
lithium	sulphur
lead	iodine
tungsten	carbon
platinum	oxygen

Q.2.7 (i) What are organic and inorganic compounds? (ii) What are acids, bases, and salts? Explain giving examples.

Answer: (i) **Organic compounds:** The compounds of carbon with other elements are called organic compounds, e.g. methane, ethane, benzene, glucose, etc. are common examples of organic compounds.

Inorganic compounds: Common examples of inorganic compounds are: NaCl, KNO₃, CaCO₃, NH₄Br, etc.

(ii) Inorganic compounds are further classified as acids, bases and salts. Hydrochloric acid (HCl), sulphuric acid (H₂SO₄), nitric acid (HNO₃), phosphoric acid (H₃PO₄) are some examples of acids. Bases are: sodium hydroxide (NaOH), potassium hydroxide (KOH), calcium hydroxide (Ca(OH)₂) etc. A compound formed by the neutralization of an acid with a base is

termed salt. A few examples are: sodium chloride (NaCl), calcium chloride (CaCl₂), barium nitrate (Ba(NO₃)₂), etc.

Q.2.8 How would you separate the following mixtures: (i) sand and water (ii) sugar and sand (iii) NaCl and NH₄Cl (iv) water and alcohol.

Answer: (i) **Sand and water:** When sand is added to water in a beaker it settles down at the bottom of the beaker (Fig. 2.2). This is called *sedimentation*. The supernatant liquid is carefully poured into another beaker with the help of a glass rod as shown in Fig. 2.3. During this process the sand at the bottom is not disturbed. This process is called *decantation*. This process of sedimentation followed by decantation is employed to separate a mixture of a liquid component and an insoluble solid component heavier than the liquid component.

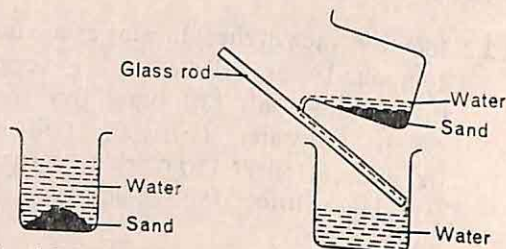


FIG. 2.2 Sedimentation

FIG. 2.3 Separation by decantation

(ii) **Sugar and sand:** Sugar is soluble in water whereas sand is insoluble. The mixture of sugar and sand is dissolved in water and allowed to stand for some time. Sand settles down at the bottom of the beaker. This is filtered through a filter paper. The residue (sand) will remain on the filter paper (Fig. 2.4). This process is called *filtration*. The liquid thus collected is called *filtrate*. This filtrate is taken in a china dish and

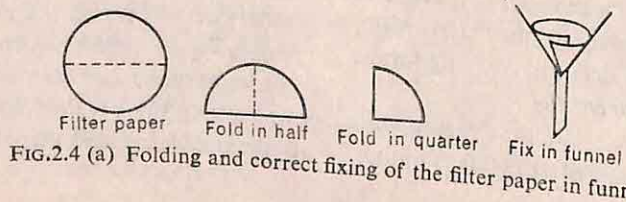


FIG.2.4 (a) Folding and correct fixing of the filter paper in funnel

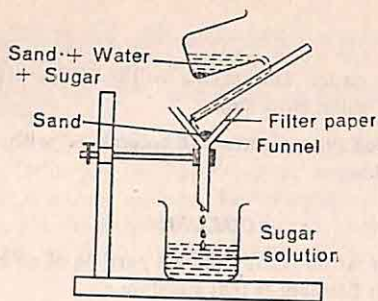


FIG. 2.4 (b) Separation by filtration

slowly heated on a wire gauze as shown in Fig. 2.5. Water evaporates and passes to the atmosphere. The residue (sugar) left in the china dish can be collected. This process is called *evaporation*.

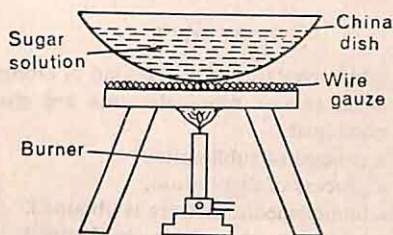


FIG. 2.5 Evaporation

(iii) NaCl and NH_4Cl : In this mixture NH_4Cl is a volatile component. On heating, it directly converts into vapour without liquifying. The vapours become solid on cooling. This process

is called *sublimation*. The mixture of NaCl and NH_4Cl is taken in a china dish and this is covered with a funnel as shown in Fig. 2.6. The stem of the funnel is plugged with cotton wool. The solid deposited on the inner side of the funnel is collected. The non-volatile sodium chloride is left in the dish.

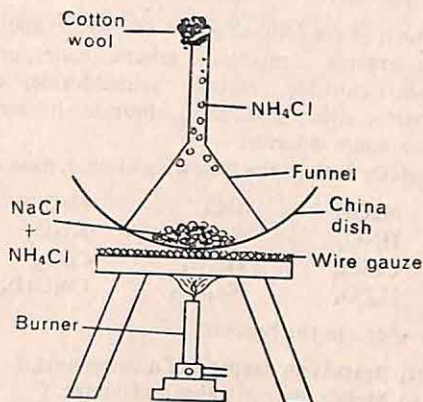


FIG. 2.6 Sublimation

(iv) *Water and alcohol*: Water and alcohol are completely miscible. Alcohol is a volatile component. This mixture is separated by a process known as *distillation*. This mixture is taken in a round bottom flask which is fitted with a thermometer and a water condenser as shown in Fig. 2.7. On heating, the alcohol vapours pass through the condensing unit where these are cooled and collected in a receiver. Water remains as residue in the flask.

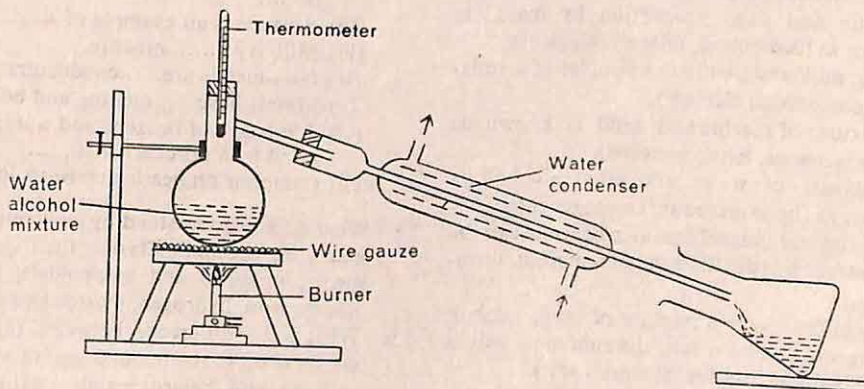


FIG. 2.7 Separation of a liquid mixture by distillation

EXERCISES

- 2.1 Classify each of the following substances as mixtures, compounds or elements.

soap	wood	rust
silver	sodium	ammonia
glucose	urea	paint
bread	fluorine	salt

- 2.2 Which of the following are inorganic and which are organic compounds: ethane, water, urea, sodium chloride, carbon tetrachloride, carbon dioxide, ether, potassium chloride, benzene and ammonium chloride.

- 2.3 Classify each of the following as acid, base or salt.

NaOH	HCl	NaCl
HNO ₃	KOH	KNO ₃
CaSO ₄	H ₂ SO ₄	CaCl ₂
H ₃ PO ₄	Na ₃ PO ₄	Co(OH) ₂

- 2.4 Put ✓ or ✗ in the brackets.

- (i) Brass is an example of a compound. ()
- (ii) Metals are malleable and ductile. ()
- (iii) Non-metals are good insulators. ()
- (iv) Glass is an example of a heterogeneous mixture. ()
- (v) Benzene is a solid organic compound. ()
- (vi) Air is a homogeneous mixture. ()
- (vii) Mercury is a liquid non-metal. ()
- (viii) A mixture of naphthalene and potassium nitrate can be separated by a process of sublimation. ()

- 2.5 Draw a line under the best answer.

- (i) A substance composed of only one type of atoms is known as (compound, mixture, element).
- (ii) A substance composed of atoms present in a definite and fixed proportion by mass, is known as (compound, mixture, element).
- (iii) Brass, milk and paint are examples of a (mixture, compound, element).
- (iv) A mixture of marble and sand is known as (homogeneous, heterogeneous).
- (v) A mixture of water and ethyl alcohol is known as (homogeneous, heterogeneous).
- (vi) A mixture of chloroform and benzene can be separated by (distillation, sublimation, filtration).
- (vii) On sublimation of a mixture of sand, sulphur, iodine and common salt, the sublimate will be (sand, sulphur, iodine, common salt).
- (viii) A mixture of sugar, sand and sodium chloride is dissolved in water filtered through a filter

paper. The residue will be (sugar, sand, sodium chloride).

- 2.6 Match the statements in column A with those in column B.

COLUMN A

- (i) Atom is the smallest particle of an element
- (ii) Element is that substance
- (iii) Metals are malleable, ductile
- (iv) Non-metals are mostly solids or gases
- (v) A compound is formed
- (vi) A mixture is a random collection of
- (vii) On mixing iron with sulphur
- (viii) By dissolving sugar in water
- (xi) A mixture of NaCl and NH₄Cl is separated by
- (x) A mixture of water and alcohol is separated by

COLUMN B

- (i) which contains only one kind of atoms.
- (ii) when two or more elements are chemically combined.
- (iii) a process of sublimation.
- (iv) a process of distillation.
- (v) a homogeneous mixture is obtained.
- (vi) a heterogeneous mixture is obtained.
- (vii) which can take part in a chemical reaction.
- (viii) and good conductors of heat and electricity.
- (ix) and poor conductors of heat and electricity.
- (x) two or more substances in no fixed ratio.

- 2.7 Fill in the blanks in the following.

- (i) An element is composed of only one type of.....
- (ii) Benzene is an example of a.....
- (iii) Milk is a.....mixture.
- (iv) Non-metals are.....conductors of electricity.
- (v) Metals have.....melting and boiling points.
- (vi) A mixture of benzene and water can be separated by a process called.....
- (vii) Camphor on heating converts into.....

- 2.8 What do you understand by an element, a mixture and a compound? Classify the following into elements, mixtures and compounds: gun powder, honey, iron, hydrogen, marble and nitre.

- 2.9 What is the difference between: (a) element and compound, (b) compound and mixture, (c) homogeneous and heterogeneous mixtures, (d) metal and non-metal.

- 2.10 How would you determine whether a given substance is a mixture or a compound?
- 2.11 How will you prove that water is a compound and not an element?
- 2.12 What is the difference between a metal and a non-metal? Classify the following as metal or non-metal: bromine, mercury, helium, sulphur, magnesium, potassium, zinc, xenon, iodine, aluminium.
- 2.13 Explain: (a) decantation, (b) filtration, (c) evaporation, (d) sublimation, (e) distillation, and (f) crystallization.
- 2.14 How would you separate the following mixtures: (a) sugar and sand, (b) sugar and water, (c) sulphur, sodium chloride and charcoal, (d) water, sand and sugar?
- 2.15 Describe various methods used for the separation of components of a mixture.

Chemical Communication

UNIT 3

Chemical Communication

D. 3.1 Molecule: The smallest particle of an element or a compound which can normally exist separately.

D. 3.2 Atomic mass: The mass of one atom of the element.

NOTE: The mass of one atom of hydrogen is 1.673×10^{-24} g. Since such figures are difficult to use in calculations, atomic masses are generally expressed in terms of atomic mass unit or relative atomic mass.

D. 3.3 Atomic mass unit (amu): one-twelfth of the mass of one atom of the isotope of carbon, carbon-12.

D. 3.4 Relative atomic mass: The number of times an atom of an element is heavier than one-twelfth of the mass of a carbon-12 atom.

NOTE: The relative atomic mass is often simply referred to as the atomic mass. This terminology is used throughout this book.

D. 3.5 Molecular mass: The number of times a molecule of the compound is heavier than one-twelfth of the mass of a carbon-12 atom.

D. 3.6 Mole: Molecular mass expressed in gram is equivalent to 1 mole. A mole contains 6.023×10^{23} molecules (Avogadro's number).

D. 3.7 Symbol: A brief representation of the name of an element.

D. 3.8 Formula: A brief representation of the composition of a compound.

D. 3.9 Chemical equation: Represents a chemical reaction with the help of symbols and formulae of the substances involved.

Q.3.1 Define the terms: (i) atomic mass (ii) atomic mass unit and (iii) molecular mass. Give examples where necessary.

Answer: *Atomic mass:* Relative masses of different atoms are expressed in terms of atomic masses. The atomic mass of an element is a numerical number which indicates how many times an atom of an element is heavier than one-twelfth of an atom of the isotope of carbon, carbon-12.

For example, 'atomic mass of hydrogen is 1.008', tells us that hydrogen atom is about one-twelfth as heavy as carbon-12 atom.

Atomic mass unit: One-twelfth of the mass of one atom of carbon -12 is known as atomic mass unit (amu). Carbon-12, an isotope of carbon, was assigned the atomic mass of 12.00 units in 1961.

Molecular mass: Molecular mass of a substance is the mass of one molecule of the substance in atomic mass units. It indicates how heavy one molecule of a substance is, compared to an atom of the isotope of carbon, carbon-12.

For example, 'molecular mass of carbon dioxide is 44', tell us that a carbon dioxide

molecule is $44/12$, i.e. 3.67 times as heavy as a carbon-12 atom.

Knowing the atomic composition of molecule and atomic masses of the elements, the molecular mass of a substance can be calculated. For example, methane molecule contains one carbon atom and four hydrogen atoms. Its molecular mass is, therefore, 16.03.

$$\begin{aligned} 1 \times \text{atomic mass of C} &= 1 \times 12.00 = 12.00 \\ 4 \times \text{atomic mass of H} &= 4 \times 1.008 = 4.03 \\ \hline &16.03 \end{aligned}$$

Q. 3.2 Discuss the Mole Concept.

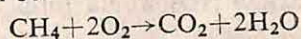
Answer: The molecular mass of oxygen is 32 amu. If this number is expressed in grams then it becomes the gram molecular mass. One gram molecular mass is equivalent to 1 mole. A mole contains 6.023×10^{23} particles. This number is known as Avogadro's number. For example, 16.00 g of oxygen or 1.008 g of hydrogen contains 6.023×10^{23} atoms; 32.00 g of oxygen or 18.16 g of water contains 6.023×10^{23} molecules.

Q.3.3 Define the terms (a) symbol (b) formula and (c) chemical equation.

Answer: (a) *Symbol:* A brief representation of the name of an element is termed symbol. For example, C stands for one atom of carbon and O stands for one atom of oxygen.

(b) *Formula:* A brief representation of a molecule or compound is called formula. For example, Cl_2 stands for one molecule of chlorine; ZnS stands for a compound, zinc sulphide.

(c) *Chemical equation:* A chemical equation represents an actual chemical reaction with the help of symbols and formulae. For example, methane burns in oxygen to form water and carbon dioxide. The chemical equation for the reaction will be:



A chemical equation is written as follows:

- (i) Write the correct formulae of the reactants on the left and separate them by plus (+) signs.

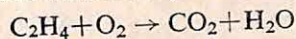
- (ii) Write the correct formulae of the products on the right and separate them by plus (+) signs.
- (iii) An arrow ($\rightarrow$) is written between the reactants and the products to indicate the direction in which the reaction takes place. This gives us a skeleton equation. To get a balanced equation, the number of atoms of various elements on both sides are equalised.

Q.3.4 Describe various methods of balancing a chemical equation.

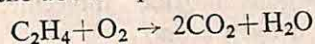
Answer: There are two methods of balancing a chemical equation (a) the hit and trial method and (b) the partial equation method.

(a) *The hit and trial method:* The various steps of this method are:

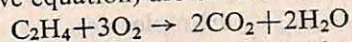
- (i) Write the skeleton equation, e.g.



- (ii) Equalise the atoms of the elements which occur at the minimum number of places (C in the above equation.)

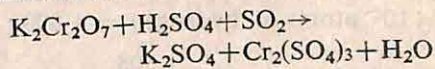


- (iii) The atoms of the elements which occur at the maximum number of places (O in the above equation) are balanced last of all.



This method can be conveniently used for simple equations only.

(b) *The partial equation method:* Equations which are difficult to balance by the hit and trial method are balanced by the partial equation method. For example,



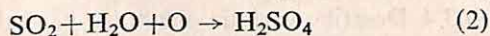
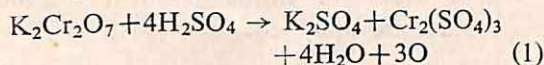
is difficult to balance by the hit and trial method. It is balanced by the partial equation method as follows:

- (i) The reaction is supposed to take place in two or more steps.
- (ii) Write partial equation for the various steps.

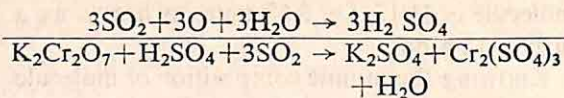
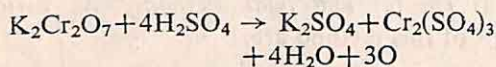
(iii) Balance the partial equations by the hit and trial method.

(iv) Add partial equations in such a way that products which are not in the final equation cancel out.

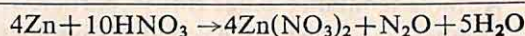
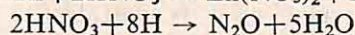
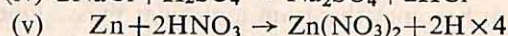
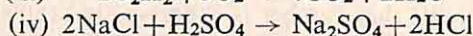
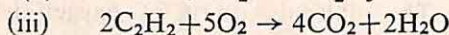
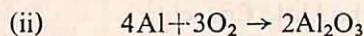
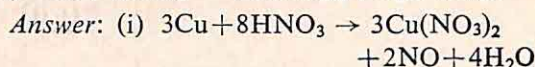
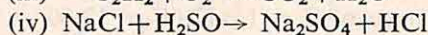
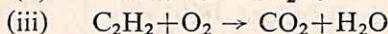
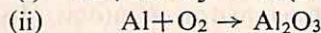
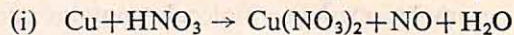
The above equation can be balanced by writing the following two partial equations and balancing them by the hit and trial method.



The product (O) which does not appear in the final equation, is cancelled out by multiplying partial equation (2) by 3 and adding. We get



Q. 3.5 Balance the following skeleton equations:



NUMERICALS

N. 3.1 Calculate the mass in grams of: (i) a carbon dioxide molecule, and (ii) a hydrogen atom.

Solution: (i) Gram molecular mass of $\text{CO}_2 = 12 + 2 \times 16 = 12 + 32 = 44 \text{ g}$.

One gram molecular mass of any substance contains 6.023×10^{23} molecules.

6.023×10^{23} molecules of $\text{CO}_2 = 44 \text{ g}$

$$\begin{aligned} 1 \text{ molecule of } \text{CO}_2 &= \frac{44}{6.023 \times 10^{23}} \\ &= 7.305 \times 10^{-23} \text{ g} \end{aligned}$$

(ii) Gram atomic mass of hydrogen is 1.008 g.

One g atomic mass of hydrogen contains

6.023×10^{23} atoms of hydrogen = 1.008 g

$$\begin{aligned} 1 \text{ atom of hydrogen} &= \frac{1.008}{6.023 \times 10^{23}} \\ &= 1.674 \times 10^{-24} \text{ g} \end{aligned}$$

N. 3.2 Calculate the number of atoms in $1.0 \times 10^{-3} \text{ g}$ of aluminium.

Solution: One g atomic mass of aluminium = 26.98 g. One g atomic mass = 1 mole

= 6.023×10^{23} atoms. Therefore, number of atoms of aluminium in $1.0 \times 10^{-3} \text{ g}$

$$\begin{aligned} &= \frac{6.023 \times 10^{23} \times 10^{-3}}{26.98} \\ &= 2.23 \times 10^{19} \end{aligned}$$

N. 3.3 For the reaction:



Calculate the mass in grams of HNO_3 that can be formed from 12.0 g of NO_2 (atomic masses are N = 14, O = 16, H = 1).

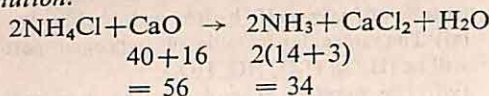
Solution: Mass of 1 mole of $\text{NO}_2 = 14 + 32 = 46 \text{ g}$.

Mass of 1 mole of $\text{HNO}_3 = 1 + 14 + 48 = 63 \text{ g}$. Thus, 3×46 or 138 g of NO_2 forms 2×63 or 126 g of HNO_3 .

Hence 12.0 g of NO_2 would form $\frac{126}{138} \times 12$ or 10.957 g of HNO_3 .

N. 3.4 Calculate the volume of ammonia at S.T.P. obtained by heating 14 g of CaO with ammonia chloride.

Solution:



1 mole of CaO or 56 g of CaO gives 2 moles of ammonia or 34 g ammonia.

14 g of CaO gives $\frac{34}{56} \times 14 = 8.5$ g of ammonia.

1 mole or 17 g of ammonia at S.T.P. occupies a volume of 22.4 litres.

Volume of 8.5 g of ammonia at S.T.P.

$$= \frac{22.4}{17} \times 8.5 = 11.2 \text{ litres}$$

N. 3.5 How many grams of iron would displace 254 g of copper from copper sulphate solution? (At. wt: Fe = 56; Cu = 63.5; S = 32).



1 mole of Cu = 63.5 g

254 g of Cu = 4 moles

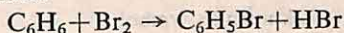
4 moles of iron will displace 4 moles of Cu

1 mole of Fe = 56 g

4 moles of Fe = 224 g

Thus 254 g of copper would be displaced by 224 g of iron.

N. 3.6 Bromobenzene, $\text{C}_6\text{H}_5\text{Br}$, can be prepared by the reaction of benzene, C_6H_6 , with bromine:



(i) If one starts with 20.0 g benzene, what is the theoretical yield of bromobenzene.

(ii) If 28.0 g of bromobenzene are actually formed in this reaction, what is the percentage yield?

Solution: (i) 1 mole $\text{C}_6\text{H}_6 = 78.0$ g

1 mole $\text{C}_6\text{H}_5\text{Br} = 157.0$ g

20.0 g $\text{C}_6\text{H}_6 = 20.0/78.0 = 0.256$ mole

From the equation it is clear that one mole of C_6H_6 could yield one mole of $\text{C}_6\text{H}_5\text{Br}$. Therefore, the theoretical yield of bromobenzene must be 0.256 mole from 0.256 mole of benzene. Theoretical yield = 0.256 mole

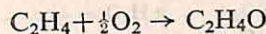
$$= 0.256 \times 157 = 40.2 \text{ g } \text{C}_6\text{H}_5\text{Br}$$

(ii) Percentage yield

$$= \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

$$= \frac{28.0}{40.2} \times 100 = 69.7\%$$

N. 3.7 For the reaction



Calculate

(i) the number of grams of $\text{C}_2\text{H}_4\text{O}$ that can be formed from 42.0 g of C_2H_4 .

(ii) the percent yield if 60 g of $\text{C}_2\text{H}_4\text{O}$ is obtained from 42.0 g of C_2H_4 .

Solution: 1 mole of $\text{C}_2\text{H}_4 = 28.0$ g

1 mole of $\text{C}_2\text{H}_4\text{O} = 44.0$ g

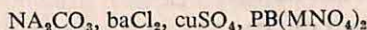
From the equation it is clear that 1 mole of C_2H_4 could yield 1 mole of $\text{C}_2\text{H}_4\text{O}$. Therefore, the quantity of $\text{C}_2\text{H}_4\text{O}$ that can be obtained from 42.0 g of C_2H_4 is

$$42 \times \frac{44}{28} = 66.0 \text{ g.}$$

$$(ii) \text{ Percentage yield} = \frac{60}{66} \times 100 = 91\%$$

EXERCISES

- 3.1 (a) What do you understand by the terms 'symbol' and 'formula'? Give their significance.
(b) Point out the mistakes in the following formulae and correct them.



(Hint: Refer to Q. 3.3)

- 3.2 Write the formulae for the following: (i) aluminium sulphate (ii) potassium nitrate (iii) sodium borate

(iv) ammonium carbonate (v) chromium chloride (vi) silver bromide (vii) mercuric sulphide (viii) zinc hydroxide (ix) bismuth iodide (x) lead phosphate.

- 3.3 (a) Rewrite the following equation in a balanced form and indicate $\text{Al}(\text{OH})_3$ as an insoluble product.

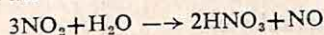


(b) Calcium carbonate on heating forms calcium oxide and carbon dioxide. Write the equation of the above reaction and indicate the evolution of the gas.

3.4 Balance the following skeleton equations:

- (i) $\text{Fe} + \text{O}_2 \rightarrow \text{Fe}_2\text{O}_3$
- (ii) $\text{H}_2\text{S} + \text{SO}_3 \rightarrow \text{S} + \text{H}_2\text{O}$
- (iii) $\text{Al} + \text{Cl}_2 \rightarrow \text{AlCl}_3$
- (iv) $\text{BaCl}_2 + \text{K}_2\text{SO}_4 \rightarrow \text{BaSO}_4 + \text{KCl}$
- (v) $\text{SO}_2 + \text{O}_2 \rightarrow \text{SO}_3$
- (vi) $\text{Cu} + \text{H}_2\text{SO}_4 \rightarrow \text{CuSO}_4 + \text{SO}_2 + \text{H}_2\text{O}$

3.5 For the reaction:



Complete the following table:

- (i) moles NO_2 + ...moles $\text{H}_2\text{O} \rightarrow$ moles HNO_3 + ...moles NO
- (ii) molecules NO_2 + ...molecules $\text{H}_2\text{O} \rightarrow$ molecules HNO_3 + ...molecules NO
- (iii) g NO_2 + ...g $\text{H}_2\text{O} \rightarrow$ g HNO_3 + ...g NO

3.6 Draw a line under the best answer:

- (i) A brief representation of the name of element. This is the definition of (symbol, formula, element, atom).
- (ii) A brief representation of a molecule or a compound. This is the definition of (symbol, formula, element, atom).
- (iii) The ions X^{3+} and Y^{2-} combine to form a compound with the molecular formula (XY , X_3Y_2 , X_2Y_3).
- (iv) The valencies of elements A and B in the compound A_1B_3 are: (+1 and -1; +3 and -1; +1 and -3).

(v) Atomic mass unit is 1/12 of the mass of one isotope of (oxygen-16, hydrogen-1, carbon-12).

(vi) The molecular formula of hydrogen peroxide will be (H_2O_2 , H_2O , HO , HO_2).

(vii) The number of molecules in one mole of water are (6.024×10^{21} , 6.064×10^{26} , 6.023×10^{23}).

3.7 Match the statements in column A to those in Column B

COLUMN A

- (i) 1/12 of the mass of one isotope of carbon atom
- (ii) Molecular mass of a substance is the mass of
- (iii) A brief representation of the mass of an element
- (iv) A brief representation of a molecule of a compound
- (v) A chemical equation represents an actual chemical reaction
- (vi) An arrow ($\rightarrow$) is written between the reactants and products to indicate
- (vii) Equations which are not balanced by the hit and trial method

COLUMN B

- (i) is called formula.
- (ii) with the help of symbols and formulas.
- (iii) are balanced by the partial equation method.
- (iv) is known as atomic mass unit.
- (v) one molecule of the substance in atomic mass units.
- (vi) is known as symbol.
- (vii) the direction in which the reaction takes place.

UNSOLVED NUMERICALS

3.1 What is atomic mass unit? Calculate the molecular mass of cane sugar ($\text{C}_{12}\text{H}_{22}\text{O}_{11}$) in amu. (Hint: Refer to Q. 3.1).

3.2 What is Avogadro's number? Calculate the number of hydrogen atoms in 6.697×10^{-24} g of hydrogen. (Hint: Refer to Q. 3.2; Ans. 4 atoms).

3.3 Calculate (i) mass of 3.0 moles of HCl , (ii) number of moles in 22 g of CO_2 ; (Ans. (i) 109.5 g; (ii) 0.5 moles).

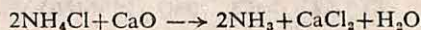
3.4 What is S.T.P.? Calculate the mass of 5.6 litres of SO_2 at S.T.P. (Hint: Refer to N. 3.4; Ans. 16 g).

3.5 Nitrobenzene, $\text{C}_6\text{H}_5\text{NO}_2$, can be prepared by the reaction of benzene, C_6H_6 , with nitric acid.



How many grams of benzene are needed to produce 15.8 g of nitrobenzene. (Ans. 10 g)

3.6 For the reaction:



Calculate the number of mole of NH_3 that can be formed from 10.0 g of NH_4Cl . (Ans. 0.187)

UNIT 4

Behaviour of Gases

L. 4.1 Boyle's law: The volume of a given mass of a gas at constant temperature varies inversely with the pressure.

L. 4.2 Charles' law: At constant pressure the volume of a given mass of a gas is directly proportional to its absolute temperature.

D. 4.3 Absolute temperature (T): Celsius temperature increased by 273.16°C ,

$$T = 273.16 + t$$

L. 4.4 Ideal gas law: $PV = nRT$
(P —pressure, V —volume, T —absolute temperature (Kelvin scale), n —number of moles of gas, R —constant)

D. 4.5 Gas constant (R): The value of R in different units is as follows: $R = 0.0821$ litre-atmosphere per kelvin per mole

$$R = 8.314 \text{ Nm K}^{-1} \text{ mol}^{-1}$$

$$R = 8.314 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$R = 8.314 \times 10^7 \text{ ergs K}^{-1} \text{ mol}^{-1}$$

$$R = 1.987 \text{ calories K}^{-1} \text{ mol}^{-1}$$

D. 4.6 Standard temperature and pressure: (STP): Standard temperature (T) is 273.16 K . Standard pressure (P) is $760 \text{ torr} = 1 \text{ atm}$.

D. 4.7 Gram molecular volume: The volume occupied by one mole of a gas at STP = $22.414 \text{ litres} = 22.414 \text{ dm}^3$. (For calculations this is generally taken as 22.4 dm^3 .)

L. 4.8 Dalton's law of partial pressure: The total pressure in a container is equal to the sum

of partial pressure of the component gases.

L. 4.9 Graham's law of diffusion: Under similar conditions of temperature and pressure, the rate of diffusion of a gas is inversely proportional to the square root of its density.

D. 4.10 Ideal gas: Any gas which obeys the various gas laws.

L. 4.11 Gay-Lussac's law of gaseous volumes: Whenever gases react under similar conditions of temperature and pressure, they always do so in volumes which bear a simple ratio to one another and to the volumes of the gaseous products.

NOTE: This law is based on experimental observations.

L. 4.12 Avogadro's law: Equal volumes of gases contain equal numbers of molecules at the same temperature and pressure.

Q.4.1 What is matter? What are the three states of matter? Illustrate with examples.

Answer: Anything which occupies space and has got weight is called matter, e.g. steel, H_2O , CO_2 .

Depending on the temperature and pressure, pure substances will exist as solids, liquids, or gases. For example, the three states of water are ice (solid), water (liquid) and water vapour (gas). Other examples are: silver, copper, sugar, wood, etc.—solids; spirit, milk, kerosene oil

etc.—liquids; and oxygen, methane, hydrogen, ammonia, etc.—gases. Solids have definite shape and volume. Liquids have definite volume but adjust their shape to the shape of the container. Gases have neither definite shape nor definite volume but change their shape and volume with change in shape and volume of the container (Fig. 4.1).

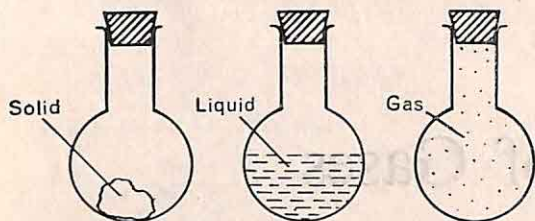


FIG. 4.1 (a) A solid has definite shape and definite volume. (b) A liquid has definite volume but adjust shape to the shape of the container. (c) A gas changes its shape and volume to the shape and volume of the container.

Q.4.2 What are the physical properties of gases?

Answer: Inter-molecular forces are the weakest in gases. On account of this, gases possess the following physical properties:

- (i) Gases have low densities.
- (ii) The molecules in gases are completely and independently mobile.
- (iii) Gases can be expanded indefinitely and will always tend to occupy their containers completely and uniformly.
- (iv) All gases mix readily with one another to form completely homogeneous solutions.
- (v) Gases exert the same pressure in all directions. Increasing the temperature of a gas in a closed container will increase the pressure of the gas.
- (vi) Gases are readily compressible.

Q. 4.3 State and explain Boyle's Law.

Answer: Robert Boyle (1627—1691) was an English philosopher. He inferred the law from experimental data in 1662. It states that: *The volume of a given mass of any gas at constant temperature varies inversely with the pressure.*

or

The product of the volume and the pressure of a given mass of any gas is a constant at constant temperature.

In a mathematical equation:

Pressure $\times$ volume = a constant (for a given mass of gas at constant T)

$PV = K$ (K is a constant at constant temperature and for a constant amount of gas)

or

$$P_1V_1 = P_2V_2$$

Boyle's law can be readily described graphically.

Fig. 4.2 represents the variation of the volume of a given amount of gas with pressure when the temperature is held constant. For different temperatures different plots are obtained. From the graphs it is clear that as the gas pressure increases the volume decreases in such a way that the product of P and V remains constant. Since every graph is plotted at constant temperature, they are also called isotherms.

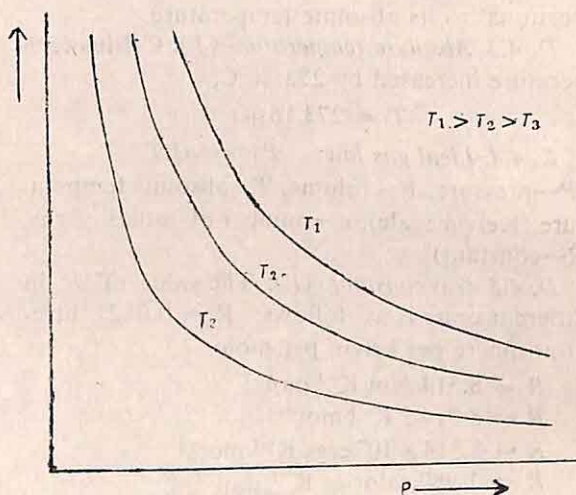


FIG. 4.2 Boyle's law—plot of P vs V at constant T .

Q. 4.4 State and explain Charles' Law.

Answer: Jacques Alexandre Charles (1746-1823) and Joseph Louis Gay-Lussac (1778-1850) were two French scientists. The law was first given by Charles in 1787 and verified by Gay-

Lussac in 1802. Generally it is now known as Charles' law. It states that: *When a gas is heated at constant pressure, the volume increases by $1/273.16$ of the volume of the gas at 0°C for each degree rise in temperature.* In a mathematical equation:

$$\begin{aligned} V_t &= V_0 + \frac{V_0 t}{273.16} \\ &= V_0 \left(1 + \frac{t}{273.16} \right) \\ &= V_0 \left(\frac{273.16 + t}{273.16} \right) \end{aligned} \quad (4.1)$$

in which V_t is the volume at $t^\circ\text{C}$ and V_0 the volume at 0°C . At $t_1^\circ\text{C}$,

$$V_1 = V_0 \left(\frac{273.16 + t_1}{273.16} \right) \quad (4.2)$$

and at $t_2^\circ\text{C}$ and the same pressure on the same sample of gas

$$V_2 = V_0 \left(\frac{273.16 + t_2}{273.16} \right) \quad (4.3)$$

Dividing (4.2) by (4.3)

$$\frac{V_1}{V_2} = \frac{273.16 + t_1}{273.16 + t_2} \quad (4.4)$$

The terms $273.16 + t_1$ and $273.16 + t_2$ would be the temperatures on the Absolute or Kelvin scale.

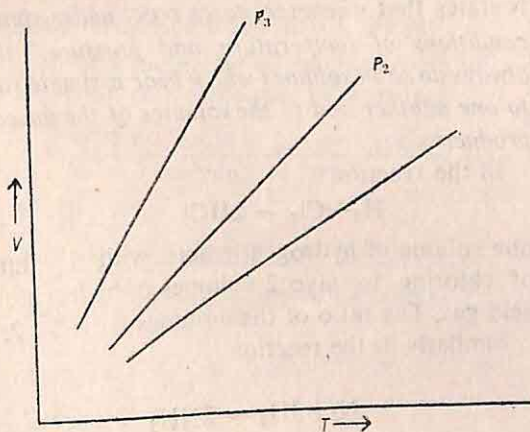


FIG. 4.3 Charles' law—plot of V vs T at constant P .

Let

$$T = 273.16 + t$$

T is called the absolute temperature. It is expressed either by $^\circ\text{A}$ or K . Generally the symbol K is used. The equation (4.4) becomes:

$$\frac{V_1}{V_2} = \frac{T_1}{T_2} \text{ or } \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

or $\frac{V}{T} = K$ (K is a constant for a given amount of gas at constant pressure).

This can be stated in words: *At constant pressure the volume of a given mass of a gas is directly proportional to its absolute temperature.*

Charles' Law can be readily described graphically. Fig. 4.3 represents the variation of the volume of a given amount of gas with temperature when the pressure is held constant. For different pressures different plots are obtained. From the graphs it is clear that as the gas temperature increases the volume also increases, in such a way that the ratio of V/T remains constant. Since every graph is plotted at constant pressure, they are also called isobars.

Q. 4.5 Derive the ideal gas equation.

Answer: The laws of Boyle and Charles can be combined to obtain a more general law for the behaviour of gases. Let P_1 , V_1 , T_1 and P_2 , V_2 , T_2 be the pressure, volume and temperature in states 1 and 2 respectively of any definite quantity of a gas. This can be done in two steps.

Step 1: At constant temperature T_1 , the pressure P_1 is changed to P_2 , the volume V_1 changes to V_x .

According to Boyle's law:

$$P_1 V_1 = P_2 V_x$$

or

$$V_x = \frac{P_1 V_1}{P_2} \quad (4.7)$$

Step 2: At constant pressure P_2 , the temperature T_1 is changed to T_2 , the volume V_x changes to V_2 .

According to Charles' Law:

$$\frac{V_x}{T_1} = \frac{V_2}{T_2}$$

$$\text{or } V_x = \frac{T_1}{T_2} V_2 \quad (4.8)$$

From Eqs. (4.7) and (4.8)

$$\frac{P_1 V_1}{P_2} = \frac{T_1 V_2}{T_2}$$

$$\text{or } \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} = \text{constant, } K$$

$$\text{In general, } \frac{PV}{T} = K.$$

Thus, for a given amount of gas PV/T is constant. The numerical value of K depends on the amount of the gas but is independent of the nature of the gas. For one mole of the gas, the constant is referred to as the molar gas constant and is denoted by R

$$\text{Therefore, } \frac{PV}{T} = R \quad (4.9)$$

where R is universal constant for all gases and is known as the gas constant. For n moles Eq. (4.9) becomes

$$PV = nRT$$

This is called the Ideal Gas Law.

Q. 4.6 Calculate the value of R in various units.

Answer: In the ideal gas law

$$PV = nRT$$

R has a numerical value which depends on the units used for pressure and volume. If the volume is expressed in litres and pressure in atmosphere, the value of R can be calculated from the fact that 1 mole of every ideal gas at STP occupies a volume of 22.414 litres.

$$R = \frac{PV}{nT} = \frac{1 \times 22.414}{1 \times 273.16}$$

$$= 0.0821 \text{ litre-atmosphere per kelvin}$$

per mole. In SI units,

$$1 \text{ atmosphere} = 1.01325 \times 10^5 \text{ Nm}^{-2}$$

$$1 \text{ litre} = 10^{-3} \text{ m}^3$$

$$\text{Therefore } P = 1.01325 \times 10^5 \text{ Nm}^{-2}$$

$$V = 0.022414 \text{ m}^3$$

$$R = 273.16^\circ \text{K}$$

$$\text{and } R = \frac{1.01325 \times 10^5 \times 0.022414}{273.16}$$

$$= 8.314 \text{ Nm K}^{-1} \text{ mol}^{-1}$$

$$= 8.314 \text{ JK}^{-1} \text{ mol}^{-1}$$

(joules per kelvin per mole)

Since 1 joule = 10^7 ergs

and 1 calorie = 4.184 joules

Therefore $R = 8.314 \times 10^7 \text{ ergs K}^{-1} \text{ mol}^{-1}$

$$R = \frac{8.314}{4.184} = 1.987 \text{ calories K}^{-1} \text{ mol}^{-1}.$$

Q. 4.7 What does STP signify? Why is it useful?

Answer: The volume of a gas varies with temperature and pressure. We therefore need to specify standard conditions in terms of temperature and pressure at which the volume can be specified. STP stands for this standard temperature and standard pressure which are taken to be 0°C or 273.16 K and 760 torr or 1 atm , respectively.

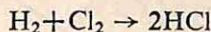
The concept is very useful since the volume of a gas measured under any conditions is converted to STP conditions. Experimentally it can be shown that under STP conditions, one mole of every gas has a volume of 22.414 litres.

Q. 4.8 (a) State and explain Gay Lussac's law of gaseous volumes.

(b) State Avogadro's law. What is the utility of this law?

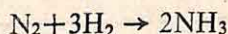
Answer: (a) Gay-Lussac's law of gaseous volumes is based on experimental observations. It states that *whenever gases react under similar conditions of temperature and pressure, they always do so in volumes which bear a simple ratio to one another and to the volumes of the gaseous products.*

In the reaction



one volume of hydrogen reacts with 1 volume of chlorine to give 2 volumes of hydrochloric acid gas. The ratio of the volumes is $1 : 1 : 2$.

Similarly in the reaction



the ratio is $1 : 3 : 2$.

(b) Amedeo Avogadro (1776-1856) was an

Italian scientist. He also believed in the earlier hypothesis of equal number of particles in equal volumes of gases, but he solved the difficulty by approaching the problem in another way and enunciated his famous law, known as Avogadro's law as follows: *Equal volume of all gases under similar conditions of temperature and pressure, contain equal number of molecules.* Mathematically,

$$N \propto V \text{ or } N/V = \text{constant}$$

here N is the number of molecules.

The law is very useful since it tells us that we may select equal numbers of molecules simply by selecting equal volumes of different gases at the same temperature and pressure.

Q.4.9 From a consideration of Avogadro's hypothesis derive a relationship between the vapour density and molecular weight of a substance.

Answer: The vapour density of a gas is the ratio between the weight of equal volumes of the gas and hydrogen under similar conditions of temperature and pressure.

$$\text{V.D.} = \frac{\text{wt. of a certain vol. of the gas or vapour at } t \text{ K and } P \text{ torr}}{\text{wt. of the same volume of hydrogen at } t \text{ K and } P \text{ torr}}$$

$\therefore$ Applying Avogadro's hypothesis, we get

$$\begin{aligned} \text{V.D.} &= \frac{\text{wt. of } n \text{ molecules of the gas or vapour}}{\text{wt. of } n \text{ molecules of hydrogen}} \\ &= \frac{\text{wt. of 1 molecule of gas or vapour}}{\text{wt. of 1 molecule of hydrogen}} \quad (i) \end{aligned}$$

Now, Mol. wt. =

$$\frac{\text{wt. of 1 molecule of substance}}{\frac{1}{12} \times \text{wt. of 1 atom of carbon-12}}$$

$\frac{1}{12} \times \text{wt. of 1 atom of carbon-12} \approx \text{wt. of 1 atom of hydrogen.}$

$\therefore \text{Mol. wt.} \approx$

$$\frac{\text{wt. of 1 molecule of the substance}}{\text{wt. of 1 atom of hydrogen}} \quad (ii)$$

Dividing (ii) by (i), we get

$$\frac{\text{Mol. wt.}}{\text{V.D.}} = \frac{\text{wt. of 1 molecule of hydrogen}}{\text{wt. of 1 atom of hydrogen}}$$

But a molecule of hydrogen contains two atoms
 $\therefore \text{Mol. wt.} = 2 \times \text{V.D.}$

The molecular weight of a substance is equal to twice its vapour density.

Q. 4.10 Discuss the mole concept.

Answer: The molecular mass of oxygen is 32 amu. If this number is expressed in grams then it becomes the gram molecular mass. One gram molecular mass is equivalent to 1 mole. A mole contains 6.023×10^{23} particles. This number (6.023×10^{23}) is known as the Avogadro's number. For example, 16.00 g of oxygen or 1.008 g of hydrogen contain 6.023×10^{23} atoms; 32 g of oxygen or 18.16 g of water contain 6.023×10^{23} molecules.

Q. 4.11 State and explain Dalton's Law of Partial Pressures.

Answer: Let us assume a gaseous mixture of A, B and C confined in a container of volume V. Applying the ideal gas law to the mixture,

$$PV = nRT \text{ or } P = \frac{nRT}{V}$$

where P is the total pressure in the container and n , the total number of moles present, equals $n_A + n_B + n_C$. If P_A , P_B and P_C are the partial pressure of A, B and C in the container, their individual contributions, when present alone in the same container at the same temperature, are given by

$$P_A = \frac{n_A RT}{V}; P_B = \frac{n_B RT}{V}; P_C = \frac{n_C RT}{V}$$

Since

$$\begin{aligned} P &= \frac{nRT}{V} = (n_A + n_B + n_C) \frac{RT}{V} \\ &= \frac{n_A RT}{V} + \frac{n_B RT}{V} + \frac{n_C RT}{V} \end{aligned}$$

therefore,

$$P = P_A + P_B + P_C$$

This is Dalton's Law of Partial Pressures.

John Dalton in 1807 stated this law as: *The total pressure in a container is equal to the sum of partial pressures of the component gases.*

Q. 4.12 What is diffusion? State and explain Graham's law of diffusion.

Answer: Separate two different gases at the same temperature and pressure by a stopcock. They will intermix when the stopcock is opened (Fig. 4.4).

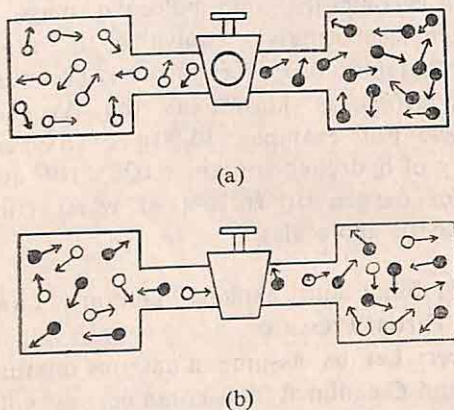


FIG. 4.4 Diffusion of two gases. (a) Before stopcock is opened. (b) After stopcock is opened

This intermixing is called diffusion. The rate of diffusion of each gas will be proportional to the average speed of its molecules. The less massive molecules will tend to move more rapidly than the heavier ones, and hence will diffuse faster. Hydrogen gas diffuses faster than oxygen.

The relation between rate of diffusion of a gas and its density was given by Thomas Graham in 1828. It states that: *Under similar conditions of temperature and pressure, the rate of diffusion of a gas is inversely proportional to the square root of its density.* This is called Graham's Law of Diffusion. If r_1 and r_2 are the rates of diffusion, and d_1 and d_2 the densities of any two gases, then

$$\frac{r_1}{r_2} = \sqrt{\frac{d_2}{d_1}}$$

Since molecular mass = $2 \times$ vapour density therefore,

$$\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$$

where M_1 and M_2 are the molecular masses of the two gases.

NUMERICALS

N. 4.1 Calculate the resulting volume when a 240 ml sample of gas is compressed at 293 K from 76 mm Hg to 4560 mm Hg.

Solution: Initially: $P_1 = 76$ mm Hg;
 $V_1 = 240$ ml

Finally: $P_2 = 4560$ mm Hg; $V_2 = ?$

Using Boyle's law: $P_1 V_1 = P_2 V_2$

Substituting: $76 \times 240 = 4560 \times V_2$

$$V_2 = \frac{76 \times 240}{4560} = 4.0 \text{ ml}$$

N. 4.2 A gas in a cylinder is compressed isothermally from 104 dm³ and at one atmosphere to 52 dm³. Find the final pressure (Note: 1 dm³ = 1 litre).

Solution: Initially: $P_1 = 1$ atm; $V_1 = 104$ dm³

Finally: $P_2 = ?$; $V_2 = 52$ dm³

Using Boyle's law: $P_1 V_1 = P_2 V_2$

Substituting: $1 \times 104 = P_2 \times 52$

$$P_2 = \frac{1 \times 104}{52} = 2.0 \text{ atm.}$$

N. 4.3 A gas in a cylinder is heated at a constant pressure of 760 mm Hg from 298 K to 596 K. If the gas initially has a volume of 24 dm³, find the final volume.

Solution: Initially: $V_1 = 24$ dm³; $T_1 = 298$ K

Finally: $V_2 = ?$; $T_2 = 596$ K

Using Charles' law: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

Substituting: $\frac{24}{298} = \frac{V_2}{596}$

$$V_2 = \frac{24 \times 596}{298} = 48 \text{ dm}^3$$

N. 4.4 Calculate the resulting temperature change when a 35 dm³ sample of gas at 298 K is isobarically expanded to 105 dm³.

Solution: Initially: $V_1 = 35$ dm³; $T_1 = 298$ K

Finally: $V_2 = 105$ dm³; $T_2 = ?$

Using Charles' law: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

$$\text{Substituting: } \frac{35}{298} = \frac{105}{T_2}$$

$$T_2 = \frac{105 \times 298}{35} = 894 \text{ K}$$

The temperature change is

$$\Delta T = T_2 - T_1 = 894 - 298 = 596 \text{ K.}$$

N. 4.5 Consider a 250 dm³ sample of gas at 300 K and 748 torr. If the volume is expanded to 317 dm³ and the pressure changed to 760 torr, what is the final temperature of the gas? (Note: 760 mm Hg = 760 torr).

Solution: Initially: $P_1 = 748 \text{ torr}$; $V_1 = 250 \text{ dm}^3$; $T_1 = 300 \text{ K}$

Finally: $P_2 = 760 \text{ torr}$, $V_2 = 317 \text{ dm}^3$; $T_2 = ?$

$$\text{We use: } \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\text{Substituting: } \frac{748 \times 250}{300} = \frac{760 \times 317}{T_2}$$

$$T_2 = \frac{760 \times 317 \times 300}{748 \times 250} = 386.6 \text{ K}$$

N. 4.6 A gas occupies 42.5 dm³ at 298 K and $1.014 \times 10^5 \text{ Nm}^{-2}$ pressure. What is the volume at STP?

Solution: Initially: $P_1 = 1.014 \times 10^5 \text{ Nm}^{-2}$; $V_1 = 42.5 \text{ dm}^3$; $T_1 = 298 \text{ K}$

Finally: $P_2 = 1.01325 \times 10^5 \text{ Nm}^{-2}$; $V_2 = ?$; $T_2 = 273 \text{ K}$

$$\text{We use: } \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\text{Substituting: } \frac{1.014 \times 10^5 \times 42.5}{298}$$

$$= \frac{1.01325 \times 10^5 \times V_2}{273}$$

$$V_2 = \frac{1.014 \times 10^5 \times 42.5 \times 273}{1.01325 \times 10^5 \times 298} = 38.94 \text{ dm}^3$$

N. 4.7 A vessel at 293 K contains nitrogen and argon at a total pressure of 3.00 atm. If the partial pressure of nitrogen is 2.30

atm., what would be the partial pressure of argon?

Solution: $P = 3.00 \text{ atm.}$; $P_{\text{N}_2} = 2.30 \text{ atm.}$; $P_{\text{Ar}} = ?$

By Dalton's law: $P = P_{\text{N}_2} + P_{\text{Ar}}$

Substituting $3.00 = 2.30 + P_{\text{Ar}}$

$$P_{\text{Ar}} = 3.00 - 2.30 = 0.70 \text{ atm.}$$

N. 4.8 In a certain experiment, 400 dm³ gas was collected over water at 298 K at a pressure of 740 torr. Calculate the pressure of the dry gas. At 298 K the vapour pressure of water is known to be 20 torr.

Solution: $P = 740 \text{ torr}$; $P_{\text{H}_2\text{O}} = 24 \text{ torr}$; $P_{\text{gas}} = ?$

Using Dalton's law: $P = P_{\text{H}_2\text{O}} + P_{\text{gas}}$

$$740 = 24 + P_{\text{gas}}$$

$$P_{\text{gas}} = 740 - 24 = 716 \text{ torr}$$

N. 4.9 A sample of CO₂ gas requires 18 seconds to pass through a small orifice into a vacuum. Under the same conditions of temperature and pressure, same amount of an unknown gas requires 45 seconds to diffuse. Find the molecular mass of the unknown gas.

Solution: According to Graham's law of diffusion

$$\frac{r_{\text{unknown}}}{r_{\text{CO}_2}} = \sqrt{\frac{M_{\text{CO}_2}}{M_{\text{unknown}}}}$$

Let X be the amount of the gases, then

$$r_{\text{unknown}} = \frac{X}{45}, r_{\text{CO}_2} = \frac{X}{18}$$

$$M_{\text{unknown}} = ?, M_{\text{CO}_2} = 44$$

Substituting

$$\frac{X/45}{X/18} = \sqrt{\frac{44}{M_{\text{unknown}}}}$$

$$\frac{18}{45} = \sqrt{\frac{44}{M_{\text{unknown}}}}$$

$$0.4 = \sqrt{\frac{44}{M_{\text{unknown}}}}$$

$$\text{Squaring both sides; } 0.16 = \frac{44}{M_{\text{unknown}}}$$

$$M_{\text{unknown}} = \frac{44}{0.16} = 275$$

EXERCISES

- 4.1 In which of the three states of matter, i.e. solid, liquid and gas, are the intermolecular forces the weakest. (*Hint*: Refer to Q. 4.2.)
- 4.2 How is pressure of a gas related to the number of its molecules at constant volume and temperature, and to its temperature when its mass and volume are constant? (*Hint*: Pressure increases with increase in number of molecules, and increase in temperature).
- 4.3 Which gas will diffuse faster and why?
(i) C_2H_2 or O_2 (ii) CH_4 or SO_2 (iii) CO_2 or C_2H_2
(iv) O_2 or SO_2 (v) NH_3 or CO_2 (*Hint*: Refer to Q. 4.9.)
- 4.4 For a mole of ideal gas, plot:
(a) A graph of P vs T at constant volume. (b) A graph of PV vs P at constant temperature. (c) A graph of PV vs V at constant temperature.
- 4.5 Put $\checkmark$ or $\times$ in the brackets.
(i) Liquids have definite shape and definite volume. ()
(ii) The intermolecular forces are weakest in gases. ()
(iii) The volume of a given mass of a gas at constant temperature varies directly with the pressure. ()
(iv) $PV = nRT$ is true for real gases. ()
(v) $R = 8.314 \text{ Nm K}^{-1} \text{ mol}^{-1}$. ()
 $R = 1.987 \text{ calories K}^{-1} \text{ mol}^{-1}$. ()
(vi) NH_3 diffuses faster than O_2 . ()
(vii) The volume occupied by one mole of N_2 at STP is more than one mole of CO_2 at STP. ()
(viii) 16g of CH_4 contains 6.023×10^{23} molecules. ()
(ix) For one mole of ideal gas, a plot of P vs T at constant volume is a straight line. ()
(x) Under similar conditions of temperature and pressure the rate of diffusion of a gas is inversely proportional to the square root of its density. ()
- 4.6 Draw a line under the best answer.
(i) Temperature remaining constant, the volume of a given mass of a gas is inversely proportional to its pressure. This is (Boyle's law, Charles' law, Ideal gas law).
(ii) $PV = nRT$. This is (Boyle's law, Charles' law, Ideal gas law).
(iii) Mathematically, Charles' law can be expressed as

$$\left(P \propto \frac{1}{V}, V \propto T, P_1V_1 = P_2V_2 \right)$$
- (iv) Volume occupied by one mole of a gas at STP is (12.4 litres, 22.4 litres, 2.24 litres).
(v) Intermolecular forces are weakest in (solids, liquids, gases).
(vi) 32 g is the mass of one mole of (oxygen, hydrogen, chlorine).
(vii) Substances which do not have definite shape and definite volume are (liquids, gases, solids).
(viii) The value of R in SI units is (0.082 litre-atom $K^{-1} \text{ mole}^{-1}$, $8.314 \text{ J K}^{-1} \text{ mole}^{-1}$).
- 4.7 Match the statements in A and B.
- A**
- (i) The volume of a given mass of a gas at constant temperature
(ii) At constant pressure the volume of a given mass of a gas
(iii) The total pressure in a container is equal to the
(iv) Under similar conditions of temperature and pressure, the rate of diffusion of a gas
(v) Equal volumes of gases contain equal number of
(vi) Anything which occupies space and has got weight
(vii) Intermolecular forces are
(viii) Increasing the temperature of a gas in a closed container
(ix) The less massive molecule will tend to move
(x) The number 6.023×10^{23}
- B**
- (i) more rapidly than the heavier ones.
(ii) will increase the pressure of the gas.
(iii) the weakest in gases.
(iv) is known as Avogadro's number.
(v) varies inversely with the pressure.
(vi) is directly proportional to its absolute temperature.
(vii) is inversely proportional to the square root of its density.
(viii) sum of partial pressures of the component gases.
(ix) is called matter.
(x) molecules at the same temperature and pressure.
- 4.8 Fill in the blanks.
(i) Anything which occupies space and has got weight is called.....

- (ii) Intermolecular forces are the ... in gases.
 - (iii) A solid has shape and volume.
 - (iv) $PV = nRT$ is true for gases.
 - (v) Gram molecular volume is litres.
 - (vi) 27°C is equal to K.
 - (vii) Temperature remaining constant the volume of a given mass of a gas is proportional to its
 - (viii) One mole of every gas at STP contains molecules.
 - (ix) Lighter gases diffuse ... than heavier gases.
 - (x) Molecular weight = ... $\times$ vapour density.
- 4.9 State and explain the law which governs the expansion of gases at constant pressure on heating. (*Hint*: Refer to Q. 4.4).
 - 4.10 Derive mathematical relationship between the pressure, volume and temperature of a given mass of a gas. (*Hint*: Refer to Q. 4.5).
 - 4.11 What is the significance of 22.414 litres of a gas?
 - 4.12 What does Dalton's law of partial pressure indicate about the behaviour of gases in a mixture?
 - 4.13 State Avogadro's law. Deduce the relationship between the vapour density and molecular weight of a substance. (*Hint*: Refer to Q. 4.8 and 4.9)

UNSOLVED NUMERICALS

- 4.1 (a) Calculate the resulting volume if a 25 ml sample of hydrogen gas is compressed at 300 K from one atmosphere to 1.25 atmosphere. (*Hint*: Refer to N. 4.1; *Ans.* 20 ml)
(b) Give the gas law on which the above calculation is based. (*Hint*: Refer to Q. 4.3)
- 4.2 A certain volume of oxygen contains 2000 molecules at 300 K. How many molecules will it contain if it is heated to 345 K and pressure remains the same? (*Ans.* No change in number of molecules)
- 4.3 What is the value of 17°C on the Kelvin scale? (*Ans.* 290 K)
- 4.4 A flask of 2.5 litres capacity can withstand pressure up to 14 atmosphere and is filled with carbon dioxide at 543 K and 760 mm pressure. At what temperature will it explode on heating? (*Ans.* 4200K)
- 4.5 Calculate the volume of one mole of oxygen at 27°C and 2 atmospheres pressure. Molar volume of oxygen at STP is 22.4 litres. (*Ans.* 12.308 litres)
- 4.6 How many moles are contained in each of the following. (i) 24.5 g of H_2SO_4 (ii) 142 g of chlorine (iii) 80 g of oxygen (iv) 24 g of hydrogen (v) 25 g of CaCO_3 . (*Ans.* (i) 0.25 mole (ii) 2.00 mole (iii) 2.5 mole (iv) 12.00 mole (v) 0.25 mole)

UNIT 5

The Structure of the Atom

D. 5.1 Matter: Anything in the form of a gas, liquid or solid that possess mass and occupies space.

D. 5.2 Atom: The smallest particle of matter which can participate in a chemical reaction.

D. 5.3 Electron: A fundamental negatively charged microparticle orbiting round the nucleus of an atom. It carries a charge of 1.6×10^{-19} coulomb. Its mass is $1/1840$ of a hydrogen atom.

D. 5.4 Proton: A fundamental positively charged microparticle contained in the nucleus of an atom. Its mass is equal to that of a hydrogen atom. It carries charge equal and opposite to that of the electron.

D. 5.5 Neutron: A fundamental uncharged particle in the nucleus of an atom. Its mass is equal to that of a hydrogen atom.

D. 5.6 Cathode rays: These rays are composed of electrons. They travel in straight lines and possess kinetic energy and momentum.

D. 5.7 Canal rays: These rays are composed of positively charged ions. They travel in straight lines and possess kinetic energy and momentum.

D. 5.8 Atomic number: The nuclear charge of an element is referred to as the atomic number of that element. For example, the number of protons contained in the nucleus of oxygen is 8, hence, nuclear charge of oxygen is 8. Thus the

atomic number of oxygen is 8.

D. 5.9 Mass number: The mass number of an element equals the number of protons plus the number of neutrons. The mass number is always a whole integer. Not all atoms of an element have the same mass number.

D. 5.10 Alpha rays: They consist of alpha particles ($\frac{4}{2}\alpha$) which contain two protons and two neutrons. An alpha particle is thus actually a helium nucleus (helium atom without its electrons, i.e. $\frac{4}{2}\text{He}$). They move with high velocity but are not very penetrating because of their heavy mass.

D. 5.11 Beta rays (${}_{-1}^0\text{e}$ or ${}_{-1}^0\beta$): They consist of fast moving electrons. They move with velocities close to that of light and are more penetrating than α -rays.

D. 5.12 Gamma rays (γ): They are electromagnetic radiation of very high energy. They are highly penetrating. They do not possess any charge.

D. 5.13 Orbit: The path of electrons around the nucleus.

D. 5.14 Energy level: Refers to the definite quantities of energy allowed in atoms depending upon the location of electrons.

D. 5.15 Electron configuration: The arrangement of electrons in the orbits (orbitals) of an atom.

D. 5.16 Valence electrons: Electrons present in the outermost orbit (highest energy level) of an element.

NOTE: Electrons present in the highest energy level take part in various chemical bond formation and chemical reactions. During the process either electrons are transferred from one atom to another (one atom acts as a donor and the other atom acts as an acceptor) or are shared between the atoms. Such electrons are referred to as the valence electrons because their number determines the valency of the atom, i.e. the combining capacity of the atom.

D. 5.17 Isotopes: Atoms that have the same atomic number but different mass numbers.

Q. 5.1 What is the evidence for two (opposite) kinds of electric charge?

Answer: Certain substances, when rubbed briskly, are capable of attracting and holding tiny bits of paper and other similar materials. Experience tells us that this attribute is different for different materials. Thus, when hard rubber (or amber or ebonite rod) is rubbed briskly with a piece of fur it will repel another piece of rubber that has been treated in a similar fashion, but it will be attracted to a piece of glass that has been rubbed with a silk cloth. Similarly, two pieces of glass, when charged in this fashion, will repel each other. A large number of such experiments have proved the possibility of two kinds of charge. Bodies bearing the same kind of charge repel each other whereas bodies bearing opposite kinds of charge attract one another. By general consensus, the charge produced on a rubber rod rubbed against fur is called 'negative' and charge produced on a glass rod rubbed against silk is called 'positive'. Hence, there are two and only two types of charges: positive and negative.

Q. 5.2 What are cathode rays? Describe experiments to show their properties and to prove that they consist of electrons.

Answer: A simple discharge experiment is performed in a glass tube provided with two

electrodes and an outlet through which the gas within the tube can be removed by means of a vacuum pump (Fig. 5.1). The gas may be air, neon, mercury vapour, helium, or any other convenient gas. On passing an electric discharge,

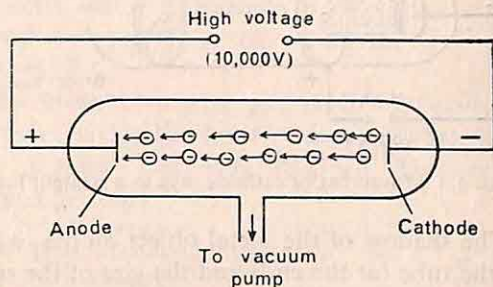


FIG. 5.1 Gas discharge tube—formation of cathode rays.

a glow is observed between the two electrodes. On lowering the pressure, the appearance of the tube changes. At sufficiently low pressure (say 10^{-2} mm of Hg) the glow disappears and there is only a greenish glow emanating from the glass in the region of the +ve (positive) electrode. If the gas pressure is reduced still further, the current ceases to flow. The glowing of the tube is said to be caused by the rays emerging from the cathode and moving towards the anode. These rays are termed cathode rays because of their origin at the cathode.

If a metallic object (metal cross) is placed between the electrodes it casts a shadow on the walls of the tube (Fig. 5.2).

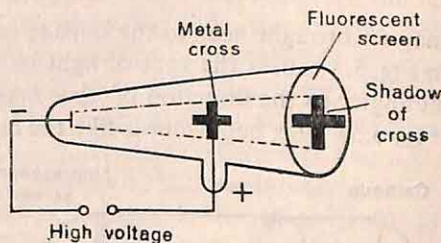


FIG. 5.2 Cathode rays cast shadow of the object in their path.

Also if a metal plate (Fig. 5.3) with a hole (anode) in it is placed in front of the cathode and the end of the tube is coated with a

fluorescent substance, a bright spot of light can be seen.

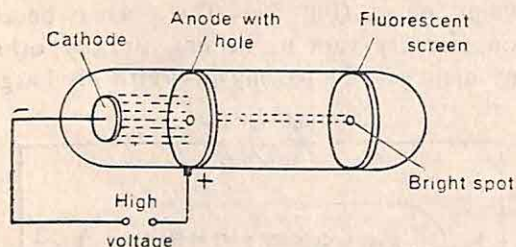


FIG. 5.3 Movement of cathode rays in a straight line.

The shadow of the metal object on the walls of the tube (at the end) and the size of the spot on the fluorescent screen compared to the size of the hole in the anode indicates that *cathode rays travel in straight lines*.

If a paddle wheel is introduced in the path of the rays, it starts rotating (Fig. 5.4) showing that *cathode rays consist of particles* which can impart their momentum to the wheel.

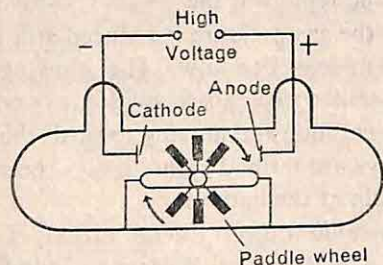


FIG. 5.4 Cathode rays possess kinetic energy.

A magnet brought near to the outside of the tube in Fig. 5.3 causes the spot of light to move at right angles to the direction of the magnetic field (Fig. 5.5). This behaviour is like the behavi-

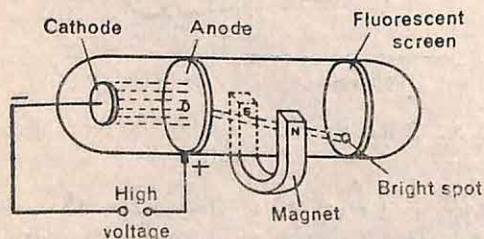


FIG. 5.5 Effect of a magnetic field on cathode rays.

our of a charged particle. The direction of the deflection suggests that the *cathode rays carry a negative electric charge*. Cathode rays are also deflected by an electric field (Fig. 5.6). The figure shows the discharge tube with two additional electrodes (sealed) in the tube. An electric voltage can be applied to these electrodes. The cathode rays move towards the positively charged electrode. This also shows that the rays carry a negative charge.

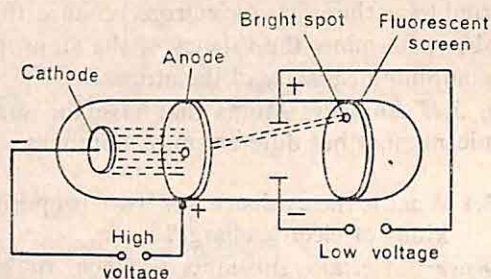


FIG. 5.6 Effect of an electric field on cathode rays.

J.J. Thomson studied the behaviour of these rays by passing them through both magnetic and electric fields and adjusting the fields such that the cathode rays strike the fluorescent screen at the same position as when neither field is present (Fig. 5.7). This experiment was used by Thomson to measure the ratio of the electric charge ' e ' to mass ' m ' of the particles in cathode rays.

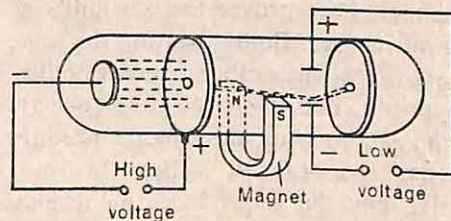


FIG. 5.7 Apparatus for measurement of e/m for the particles constituting cathode rays.

Thomson performed a series of experiments by changing the metal of electrodes and by placing different gases in the tube. In all the arrangements, the charge to mass ratio, e/m , for cathode rays was always the same.

This shows that such negative particles form a common constituent of all gases. This has been found to hold good for other form of matter also. This fundamental negative particle is named the *electron*.

Q. 5.3 Describe an experiment to determine the sign of the charge on an electron.

Answer: Refer Q. 3.2; Effect of magnetic and electric fields on cathode rays.

Q. 5.4 Give a brief account of the discovery of canal rays and protons.

or

How can the existence of positively charged particles in the atom be established?

or

Which experiments give evidence that atoms contain proton?

Answer: The atom as a whole is electrically neutral. Now if atoms contain negatively charged particles, they should also possess positively charged particles.

Evidence to this came from the gaseous discharge tube experiment with negative electrode (cathode) having holes (perforated cathode) (Fig. 5.8). At sufficiently low pressure a faint glow of light is observed behind the cathode. This glow is caused by the rays emanating through the perforated cathode. It is observed that these rays move towards the cathode and pass through the holes in the cathode.

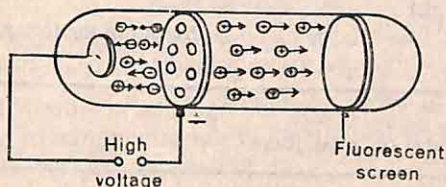


FIG. 5.8 Production of canal rays.

These rays are called *canal rays* and are composed of particles. These particles are, however, quite different from the electrons. Their behaviour in electric and magnetic fields indicates that they carry a positive electric charge.

Thomson measured the charge to mass ratio, e/m , for these particles. The ratio was found to be much smaller than e/m for electrons. The e/m values depended on the gas in the discharge tube. Thus, these were found to be massive particles, being of the same order of mass as the atoms or molecules of which the gas was composed.

By using hydrogen gas, positively charged particles having the lowest mass, and therefore, the highest e/m were obtained. They were termed protons.

$$\text{H} \xrightarrow[\text{energy}]{\text{electrical}} \text{H}^+ + e^-$$

hydrogen atom hydrogen ion electron

If the tube contains neon instead, the cathode rays are still the same, but now the canal rays are composed of positively charged neon atoms (neon ions).

$$\text{Ne} \xrightarrow[\text{energy}]{\text{electrical}} \text{Ne}^+ + e^-$$

Q. 5.5 How was the existence of neutrons established within the atom? How has this been able to solve the problem of atomic mass?

Answer: Earlier to Rutherford, the atom was believed to be formed of electrons and protons only. Under these circumstances the atomic weight of an element should be equal to the total mass of electrons and protons present within the atom. Thus, the mass of the atom should be primarily due to protons only as electrons are particles of negligible mass. But this analogy does not go well with the known facts. For example, the atomic number of nitrogen is 7. Therefore, there are 7 protons in nitrogen atom and its atomic weight should be 7. However, the atomic weight is found to be 14. Similar disagreements arose with other elements. Rutherford (1920) suggested that in addition to the two charged particles in an atom, there was the possibility of the presence of a particle of essentially the same mass as that of proton but without any charge.

Chadwick established the existence of such material particles called 'neutrons' on the basis of experimental observations. The protons and the neutrons account for the atomic mass (mass of nucleus).

- Q. 5.7** (a) What are the fundamental building units of all matter? Give their masses and the charge carried by each; also give their location in the atom.
(b) Compare and contrast cathode rays and canal rays.

Answer : (a) The atom is composed of three basic subatomic particles (fundamental particles), namely the electron, the proton, and the neutron. The characteristics of these three particles are given below in Table 3.1.

(b) The characteristics of cathode rays and canal rays are given below in Table 3.2.

- Q. 5.6** (a) Define unit negative charge and unit positive charge. (b) Name and differentiate between radiations emitted by naturally occurring radioactive elements.

Answer: (a) The present day accepted value for the charge on the electron is 1.6×10^{-19} coulombs. This charge carried by the electron is the smallest in magnitude that can exist in nature and is known as a unit negative charge.

The number of electrons associated with each atom is just sufficient to balance the positive charge, so that as a whole the atom is neutral.

The unit of positive charge will thus be an amount of charge exactly equal in magnitude but opposite in sign to the unit negative charge.

(b) Some elements like uranium, radium, etc. naturally emit energy in the form of radiations. This property associated with such elements is called radioactive decay. The energy released in radioactive decay may be in three forms.

(i) In some elements high speed electrons are released. These electrons are called β -rays. Thomson studied them in gas discharge tubes.

(ii) In some elements, rays similar to X-rays are produced. These are named γ -rays. They are electromagnetic rays and do not carry any charge.

TABLE 3.1 PROPERTIES OF PARTICLES

Particle	Mass	Charge	Symbol	Location
Electron	1/1840 of a hydrogen atom	Negative charge; 1.6×10^{-19} coulomb (1 unit)	e	Rotates round the nucleus in fixed orbits
Proton	Equal to that of a hydrogen atom	Positive charge; equal and opposite to that of electron (1 unit)	p	Present in the nucleus
Neutron	Equal to that of a hydrogen atom	No charge	n	Present in the nucleus

TABLE 3.2 PROPERTIES OF CATHODE AND CANAL RAYS

S. No.	Cathode rays	Canal rays
1.	Composed of negatively charged particles called electrons	Composed of positively charged ions
2.	Travel in straight lines	Travel in straight lines
3.	Possess kinetic energy and momentum	Possess kinetic energy and momentum
4.	e/m of their particles is always the same	e/m of their particles depends upon the nature of gas

(iii) Some elements release energy in the form of slow speed particles. These are named as α -particles. They have a positive electric charge of two units, $2+$, and have much higher mass than β -rays. They are helium particles that have lost two electrons.

Q. 5.7 Discuss the significance of Rutherford's experiment in the advancement of atomic structure.

or

Describe an experiment which leads to infer that :

- the whole mass of an atom is centred at the nucleus of the atom,
- the central part of the atom, i.e. the nucleus has all the positively charged particles.

Answer : In 1911 Rutherford directed a beam of α -rays emanating from a radioactive material towards a thin strip of gold (Fig. 5.9) and determined the subsequent path of the particles.

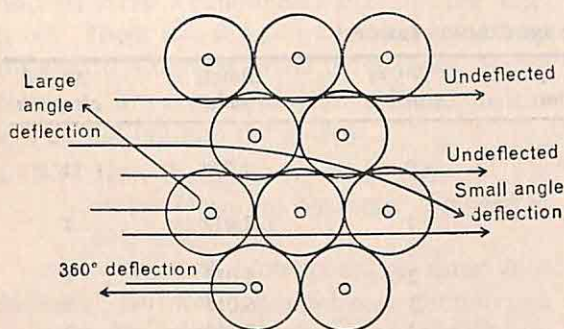


FIG. 5.9 The scattering of α -particles by a gold foil made up of atoms.

A fluorescent screen was set up around the foil. He made the following observations :

- Most of the high energy α -particles passed straight through the metal foil to hit the fluorescent screen;
- Some particles were deflected through a small angle from their original paths as they encountered the target;
- A few α -particles were deflected through very large angles; and
- Very few actually bounced back in the direction from which they came.

Rutherford reasoned as follows : since most of the particles pass through the gold strip without deflection, this shows that there is a lot of empty space within an atom.

The angles by which the individual particles are deflected vary widely. Large angle deflections reveal the following :

- Positively charged particles are deflected due to collision with a centre of very high charge within the atom;
- The centre of high charge is positively charged hence the positively charged α -particles are repelled by it.
- The fact that very few α -particles are deflected through large angles shows that the positive charge is contained in a very small space, known as the nucleus;
- Most of the mass resides in the nucleus.

Thus, Rutherford's experiment shows that the mass of an atom and its positive charge are concentrated in a nucleus. The negative charge carried by electrons is spread throughout a much larger volume around the nucleus to maintain electrical neutrality.

Q. 5.8 What is the 'nucleus' of an atom? What information can be had from it?

Answer : Rutherford pictured the nucleus as follows.

Nearly all the mass of an atom and its positive charge are concentrated in a small region. Thus, all the protons and neutrons must be present in this region, and hence, it is positively charged. This small region (dense central core) is known as the 'nucleus'.

From Rutherford's model it is clear that the positive charge on the nucleus of an atom is always an integer. Moreover the nuclear charge corresponds exactly to the position of an element in the periodic table. Thus, the number of protons present in an atom of an element corresponds to the number of positive charge on the nucleus. This numerical value is called the *atomic number* of the element. Thus, the atomic number of an element is equal to the

positive charge (number of protons) in its nucleus.

The total number of protons and neutrons contained in the central core (nucleus) of an element is called its *mass number*. Electrons revolve around this nucleus, in fixed orbits or energy levels. The number of electrons is equal to the number of protons present in the nucleus, so that electrical neutrality is maintained.

Q. 5.9 What are isotopes?

Answer : The atomic number of an atom is equal to the number of protons in the nucleus, while the mass number equals the number of protons plus the number of neutrons. All atoms of an element have the same atomic number, but not the same mass number. Atoms that have the same atomic number but different mass numbers are called *isotopes*. Isotopes have the same number of protons (same atomic number) but different number of neutrons in the nucleus. For

example, hydrogen is an element with atomic number 1. All hydrogen atoms have 1 proton in their nuclei. Hydrogen atoms having mass number 1, 2 and 3 are known. Hence there are three isotopes of hydrogen. Table 3.3 summarizes the composition of some common isotopes.

Q. 5.10 (a) Helium, as found in nature, consists of two isotopes. Most of the atoms have a mass number 4, but a few have a mass number 3. For each isotope indicate the : (i) atomic number (ii) number of protons (iii) number of neutrons (iv) mass number (v) nuclear charge.

(b) What is the relation between atomic mass, atomic number and number of neutrons in an atom of an element? Explain with examples.

TABLE 5.3 COMPOSITION OF SOME COMMON ISOTOPES

Isotopes	At. no.	Mass no.	No. of protons	No. of neutrons	Atomic weight	No. of electrons
Hydrogen—1 (Protium)	1	1	1	0	1.008	1
Hydrogen—2 (Deuterium)	1	2	1	1	2.014	1
Hydrogen—3 (Tritium)	1	3	1	2	3.022	1
Lithium—6	3	6	3	3	6.015	3
Lithium—7	3	7	3	4	7.016	3
Carbon—12	6	12	6	6	12.000	6
Carbon—13	6	13	6	7	13.003	6
Nitrogen—14	7	14	7	7	14.003	7
Nitrogen—15	7	15	7	8	15.000	7
Oxygen—16	8	16	8	8	15.995	8
Oxygen—17	8	17	8	9	16.999	8
Oxygen—18	8	18	8	10	17.999	8
Chlorine—35	17	35	17	18	34.970	17
Chlorine—37	17	37	17	20	36.970	17

TABLE 5.4

Isotope	At. no.	No. of protons	No. of neutrons	Mass number	Nuclear charge
Helium—3	2	2	1	3	2
Helium—4	2	2	2	4	2

Answer : (a) See Table 5.4.

(b) Atomic mass – atomic number = number of neutrons.

For example the atomic mass of oxygen is 16 and its atomic number is 8. Thus, oxygen has $16 - 8 = 8$ neutrons. Similarly for a fluorine atom.

$$\begin{array}{rcc} 19 & - & 9 = 10 \\ \text{Atomic mass} & & \text{Atomic number} \\ \text{Neutrons} & & \end{array}$$

Q. 5.11 'The negatively charged particles in an atom are found outside the nucleus'. Explain.

Answer: According to the present concept of the atom, the atom is composed of two parts, i.e. nucleus and extra-nuclear part. The protons and neutrons are contained in the nucleus and the electrons revolve round the nucleus in certain stationary energy levels (orbits). This gives rise to centrifugal force. At the same time the nucleus exerts a coulombic force on the electrons. These two forces are balanced and keep the electrons moving round the nucleus. Hence electrons are always found outside the nucleus and do not fall into the nucleus.

Q. 5.12 Describe the present concept of an atom. How are electrons arranged in an atom?

Answer: An atom is composed of three fundamental particles, i.e. electrons, protons and neutrons. The protons and neutrons are all contained in the small central core or nucleus (diameter 10^{-12} cm). Surrounding this nucleus are the electrons moving around the nucleus in regularly defined orbits, just as the planets move in regular orbits around the sun (Fig. 5.10).

The electrons are distributed into different energy levels K, L, M, N, etc.; according to their energy. The energy levels can be represented by numbers 1, 2, 3, 4, ... The energy level nearest to the nucleus has the lowest energy. As the distance of the orbit from the nucleus increases, its energy also increases correspondingly.

The maximum number of electrons to be

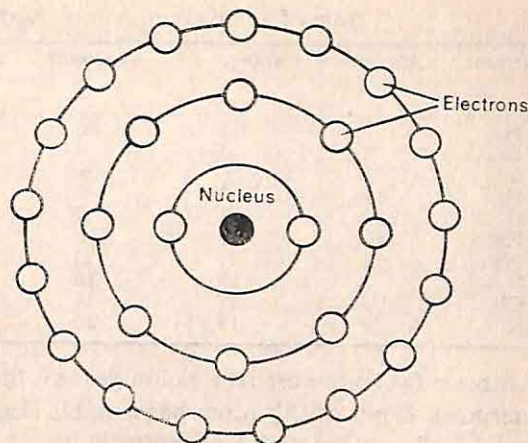


FIG. 5.10 Atomic model

accommodated in any orbit is given by $2n^2$ where n represents the number of the orbit (n is called the principal quantum number; its values are 1, 2, 3, 4, ... These values refer to the orbits). Thus, the maximum number of electrons in the first orbit ($n = 1$) is 2; in the second orbit ($n = 2$) is 8; in the third orbit ($n = 3$) is 18; and so on. The number of protons, neutrons and electrons and the arrangement of electrons for a few elements are given in Table 5.5 on p. 32.

Q. 5.13 (a) Which of the following electronic configurations represents a noble gas and why? (i) 2, 8, 8 (ii) 2, 8, 4.
(b) Consider the following table.

	Protons	Neutrons	Electrons
A	17	18	17
B	18	22	18
C	7	7	7
D	17	20	17
E	8	8	8

Choose from the table the letters (A to E) that represent (i) an atom of a noble gas, (ii) a pair of isotopes, (iii) an element having a mass number of 14, and (iv) an element carrying 6 electrons in the outermost orbit.

TABLE 5.5 NUMBER OF ATOMIC PARTICLES AND ELECTRONIC CONFIGURATIONS

Element	Mass no.	Atomic no.	Neutrons	Protons	Electrons	Electronic configuration			
						K	L	M	N
H	1	1	0	1	1	1			
Li	7	3	4	3	3	2	1		
C	12	6	6	6	6	2	4		
N	14	7	7	7	7	2	5		
O	16	8	8	8	8	2	6		
Ne	20	10	10	10	10	2	8		
Na	23	11	12	11	11	2	8	1	
S	32	16	16	16	16	2	8	6	
Cl	35	17	18	17	17	2	8	7	
K	39	19	20	19	19	2	8	8	1

Answer: (a) (i) represents a noble gas as the outermost orbit of this atom has a stable electronic configuration with 8 electrons in it.

(b) (i) B is a noble gas as its last orbit will have 8 electrons.

(ii) A and D are isotopes as they have the same atomic number but different atomic mass.

(iii) C corresponds to an element having a mass number of 14.

(iv) E corresponds to an element having 6 electrons in the outermost orbit.

Q. 5.14 (a) Which of the following is correct?

The atomic number of an element does not account for: (i) number of positive charges in the nucleus, (ii) position in the periodic table, (iii) number of negative charges in the extra-nuclear region, (iv) number of neutrons in the nucleus.

(b) Which of the following is false?

(i) Chadwick discovered the neutron.
(ii) Atoms contain a very small nucleus which has a positive charge. (iii) The number of protons plus the number of

electrons equal the mass number of the atoms. (iv) The electrons in an atom can occur only in certain energy levels. (v) Atoms have zero electric charge.

Answer: (a) (iv); (b) (iii)

Q. 5.15 (a) Which of the following is correct?

The addition of a neutron to the nucleus of an atom would (i) affect the chemical nature, (ii) increase the mass number, (iii) affect the number of charges in the nucleus, (iv) alter atomic number, (v) decrease the number of electrons.

(b) Consider these two electronic arrangements for neutral atoms.

A : 2(K) 8(L) 1(M)

B : 2(K) 8(L) 1(N)

Which of the following is false? (i)

Energy is required to change A to B.

(ii) A represents a sodium atom. (iii) A

and B represent different elements.

(iv) Less energy is required to move one electron from B than from A.

Answer: (a) (ii); (b) (iii)

EXERCISES

5.1 List the number and kind of fundamental particles present in a neutral nitrogen atom that has a nucleus with a nuclear charge seven times that of a hydrogen nucleus and with approximately fourteen times the mass. (Ans. Proton 7, Electron 7, Neutron 7).

5.2 Complete Table 5.6 on p. 33.

5.3 Name the elements that correspond to each of the following electron configurations :

2, 1; 2, 3; 2, 8; 2, 8, 1; 2, 8, 1; and 2, 8, 8, 2

(Hint : Refer to Q.5.12)

TABLE 5.6

Element	Atomic number	Particle per atom			Mass number
		Protons	Electrons	Neutrons	
Aluminium	13	—	—	—	27
Beryllium	—	4	—	—	9
Sodium	11	—	—	—	23
Calcium	—	—	20	20	—
Carbon	—	6	—	6	—
Fluorine	—	—	9	—	19
Sulphur	16	—	—	16	—
Iodine	—	—	53	—	127

- 5.4 Write the electronic arrangement for the elements with atomic numbers 7, 9, 13 and 20 respectively. (Hint : Refer to Q.5.12)
- 5.5 Write the energy configurations of fluorine and chlorine. In what ways are they related to that for bromine? (Hint : Number of valence electrons is the same)
- 5.6 An oxygen atom contains 6 electrons and 6 protons. What other particles are needed to account for the known mass of oxygen-16 atom? Give their name and number.
- 5.7 In what way does the argon atom (atomic number 18, atomic weight 39) differ from the potassium atom (atomic number 19, atomic weight 39).
- 5.8 What determines the number of electrons outside the nucleus?
- 5.9 State the relationship between the number of electrons of a neutral atom and its atomic number.
- 5.10 Which of the following statements is false? The atoms of chlorine differ from the atoms of every other element in the following ways:
- The nuclei of chlorine atoms have a different number of protons than the nuclei of any other element;
 - Atoms of chlorine have a much higher ratio of neutrons to protons than the atoms of any other element;
 - Neutral atoms of chlorine have a different number of electrons than neutral atoms of any other element;
 - Atoms of chlorine have different chemical behaviour than do atoms of any other element.
- [Ans. (ii)]
- 5.11 Which of the following pairs are isotopes? Elements containing
- 17 protons, 18 neutrons
17 protons, 20 neutrons
 - 6 protons, 6 neutrons
7 protons, 6 neutrons
- (iii) 8 protons, 8 neutrons
8 protons, 10 neutrons
[Ans. (i) and (iii)]
- 5.14 Fill in the blanks :
- Cathode rays are.....
 - The..... and are present in the nucleus.
 - The number of determines the atomic number.
 - Isotopes of an element differ in the number of
 - An is a region around the nucleus in which an may most probably be found.
- (Ans. (i) electrons, (ii) protons, neutrons (iii) protons, (iv) neutrons, and (v) energy level, electron)
- 5.15 Describe an experiment to determine the sign of the charge of an electron. (Hint : Refer to Q 5.2)
- 5.16 How will you prove that electrons are a common constituent of matter?
- or
- 'All atoms contain electrons'. What evidence is there for this statement. (Hint : Refer to Q. 5.2)
- 5.17 Write short notes on (i) cathode rays, (ii) mass number, and (iii) valence electrons.
- 5.18 'There is no electric charge on the atom of an element.' Justify the statement. (Hint : Every atom has equal number of protons and electrons)
- 5.19 'Electrons are negatively charged particles.' Explain by giving evidence. (Hint : Refer to Q. 5.2)
- 5.20 How do isotopes of one element differ from each other? How are they the same? (Hint : Mass is different. Atomic number is the same.)
- 5.21 How would you describe the structure of atoms to a friend who knows nothing about them?
- 5.22 Describe electrons, protons and neutrons with reference to charge, mass and location.
- 5.23 Explain the meaning and significance of the following statements :
- Isotopes of an element have the same atomic number

- (b) The reactivity of an atom is determined by its electronic configuration.
 - (c) There is no definite relationship between atomic number and atomic weight.
 - (d) Electrons move only in certain definite orbits.
- 5.24 How will you prove that :
- (i) Cathode rays consist of material particles;
 - (ii) Electrons are negatively charged; and
 - (iii) Electron is an essential constituent of matter.
- (Hint : Refer to Q.5.2)
- 5.25 What do you understand by valency of an element? How is it determined? Arrange the following in increasing order of valency: nitrogen, oxygen, calcium, aluminium and carbon.
- 5.26 State the facts which led to a belief that matter also contains neutral particles.
- 5.27 (a) Why does the charge to mass ratio of positive rays depend upon the gas in the electric discharge tube?
 b) Charge to mass ratio of cathode rays is independent of the nature of gas in the discharge tube. Comment.

UNIT 6

Chemical Bonding

D.6.1 Inertness (of noble gases): The inertness of noble gases is ascribed to their stable electronic configuration.

D.6.2 Chemical bond: The chemical force which keeps the atoms in any molecule together.

D.6.3 Ions: An atom or molecule that carries a positive or negative charge because of deficiency or excess of electrons.

D.6.4 Cation: An ion which carries positive charge.

D.6.5 Anion: An ion which carries negative charge.

D.6.6 Ionic (electrovalent) bonding: Refers to the bonding of atoms in compounds due to attraction between cations and anions. It is established by the transfer of electrons from one element to another.

D.6.7 Covalent bond: A bond that results when two atoms are bound together through the sharing of a pair of electrons.

D.6.8 Single bond: The covalent bond that results when one pair of electrons is shared between two atoms.

D.6.9 Double bond: The covalent bond that results when two pairs of electrons are shared between two atoms.

D.6.10 Triple bond: The covalent bond that

results when three pairs of electrons are shared between two atoms.

D.6.11 Multiple bonding: The covalent bond that results when two or more pairs of electrons are shared between two atoms.

D.6.12 Polarity: Occurs in a covalent bond when the two atoms exert different degrees of attraction for the shared electrons.

D.6.13 Polar molecules: Molecules in which the positive and negative centres are not evenly distributed.

Q.6.1 (a) What is a chemical bond? Explain.

(b) What are the basic assumptions for compound formation?

Answer: (a) Atoms combine to form molecules. Electrical forces hold atoms together in molecules. Both attractive and repulsive forces are simultaneously present between atoms. A molecule forms if the forces of attraction are stronger than the forces of repulsion. Thus, the attractive force is termed as *chemical bond*.

(b) The electrons in the outermost shell are the only ones that will be directly involved in compound formation.

Stable molecules are generally formed if each atom acquires a stable electron configuration. The most stable electron configuration is that of an inert gas.

Q.6.2 Discuss the 'chemical inertness' of the noble gases.

Answer: Chemical inertness of the noble gases is due to their stable electronic arrangement. All the noble gases except helium contain 8 electrons in their outermost shell. Helium has only 2 electrons. The outermost shell in each of these cases has the maximum number of electrons it can hold. This structure has a very high ionization energy and very low electron affinity. Hence it is very stable. Therefore, under normal circumstances the noble gases show no combining capacity.

(Recently, however, some compounds have been formed with these gases. The modern terminology for these is therefore 'noble gases' and not 'inert gases'.)

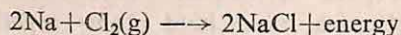
Q.6.3 (a) By what mechanism are ionic compounds formed?

Or

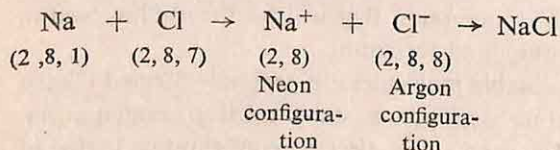
What do you understand by an ionic bond?

(b) Which families of elements tend to form ionic bonds?

Answer: (a) Ionic bonding occurs when elements gain or lose electrons to form ions. As a result of transfer of electrons, ions acquire stable electronic configurations similar to those of the noble gases. For example, when chlorine gas is brought in contact with hot sodium metal, sodium chloride is formed.



In the reaction between sodium and chlorine, ions with opposite electric charges are formed. Sodium atom loses an electron to form Na^+ ion (cation) and chlorine atom gains that electron to form Cl^- ion (anion).



The number of plus and minus signs in these

formulae indicate the number of electrons lost or gained.

The ions attract each other because they have opposite electric charge. The stability of an ionic solid depends upon the electrostatic interaction between the ions. The bond so formed is called the *ionic bond*.

(b) The electron configuration of an element helps us to decide about the elements taking part in ionic bond formation. Generally the elements which can donate electrons easily, i.e. electropositive (metallic) elements like Li, Na, K, Rb, Be, Mg, Ca, Sr, Ba, etc., and the elements which can accept the electrons easily, i.e. electronegative (non-metallic) elements like F, Cl, Br, I, S, O, etc., form ionic bonds and hence ionic solids.

Q.6.4 (a) List the various characteristics of ionic compounds.

(b) Which of the many electrons are involved in the bond formation? Explain.

Or

How is valency of an atom related to its electronic configuration?

Answer: (a) Ionic compounds have the following characteristics:

- (i) Their ions are held together by strong electrostatic forces.
- (ii) They have high melting and boiling points.
- (iii) They act as good conductors of electricity in the molten state because ions are present in the melt.
- (iv) They are mostly soluble in water.
- (v) They ionize in solution.
- (vi) Aqueous solutions of ionic compounds are good conductors of electricity because ions are present in these solutions.

(b) Most of the compounds are formed in two ways:

- (i) By transfer of electrons from the atoms of one element to those of the other to produce ions.

- (ii) By sharing of electrons between two or more atoms.

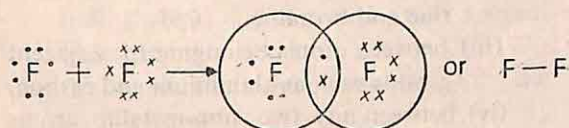
In either case the atoms acquire electron configurations like those of noble gases.

Electrons belonging to the outermost energy level are the most suitable for bond formation as they are not held strongly by the nucleus. Being loosely bound, they are available for bond formation. Secondly the outermost electrons of an atom are very close to any other atom which may combine with it.

As the electrons present in the outermost shell are responsible for bond formation, these are called valence electrons. These electrons determine the valency of the element.

Q.6.5 Discuss the formation of a covalent bond.

Answer: In a covalent bond atoms are bonded together to form molecules by sharing equal number of valence electrons. One or more pairs of electrons are held in common by the combined atoms. Each atom in the compound acquires an electron configuration similar to one of the noble gases. For example, the fluorine atom has the electronic structure 2, 8, 7. The molecule of fluorine has two atoms. A stable electronic configuration is possible only when one electron from each is contributed for sharing. Thus,



(2, 8, 7) (2, 8, 7) (2, 8, 8) (2, 8, 8) Single

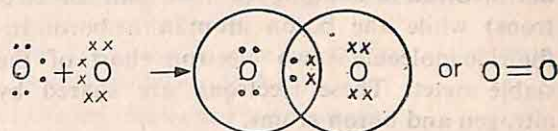
covalent bond

Covalent bonds are formed both by similar and dissimilar atoms, e.g. Cl_2 and HCl .

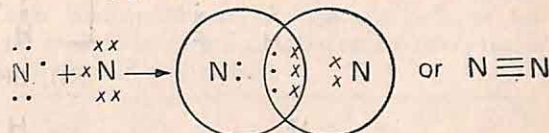
The sharing of two electrons, one electron being provided by each atom, constitutes a single covalent bond. It is usually represented by a single line as shown above.

The oxygen atom has six electrons in its outermost shell and in the oxygen molecule, O_2 , a stable electronic configuration can be achieved

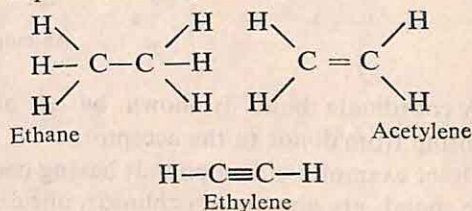
if two electrons are contributed by each atom for sharing. The oxygen atoms are bound together by a double bond as shown below by a double line.



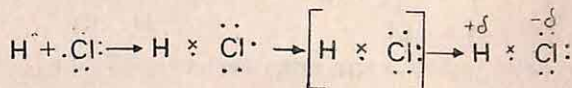
Similarly, the nitrogen molecule has a triple bond, which involves the sharing of six electrons, three being given by each nitrogen atom.



The bonding in three hydrocarbons, ethane, ethylene and acetylene illustrate single, double and triple bonds respectively.



When the two atoms that are joined together by covalent bonds are not identical, the electrons are not equally shared. For example, in hydrogen chloride, the chlorine atom has a greater affinity for electrons than does the hydrogen atom (chlorine is more electronegative than hydrogen) and the electron pair forming the bond is shifted towards the chlorine atom. Thus, the molecule acquires an electrical dipole. The bond present is called a polar covalent bond.



Q.6.6 What is the coordinate or dative covalent bond?

Answer: This bond is quite identical to the covalent bond, except that only one atom

TABLE 6.1

<i>Ionic compound</i>	<i>Covalent compound</i>
1. Bonds are formed by transfer of electrons from the atoms of one element to those of the other. 2. The crystals are a network of ions (cations and anions) held together by electrostatic attraction. 3. Have high melting and boiling points. 4. Are usually soluble in polar solvents such as water. 5. Melts or solutions permit the passage of electric current.	1. Bond results from the sharing of pairs of electrons by two or more atoms. 2. The crystals are made up of molecules held together by weak intermolecular forces. 3. Have low melting and boiling points. 4. Are usually soluble in non-polar solvents such as CCl_4 , CHCl_3 , CS_2 , etc. 5. Charged ions are absent in covalent molecules, hence, they do not conduct electricity in the liquid state. Solutions of covalent compounds in water are poor conductors unless the covalent substance reacts with water to produce ions.

(b) In general, what conditions cause two atoms to combine to form (i) a pure covalent bond, (ii) a pure ionic bond.

Answer: (a) Refer to Q.6.8

(b) (i) Refer to Q.6.5 and Q.6.7(b)

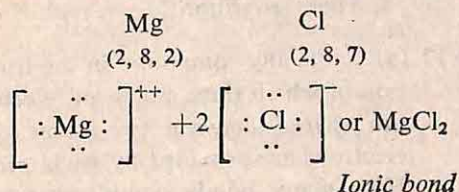
(ii) Refer to Q.6.3.

Q.6.10 (a) Write electronic formulae (electron dot structure) for the following compounds. Also indicate the nature of bonds formed: (i) magnesium chloride, (ii) carbon tetrachloride, (iii) chloroform, (iv) water, (v) calcium oxide, (vi) hydrogen sulphide, (vii) carbon dioxide, and (viii) sodium hydroxide.

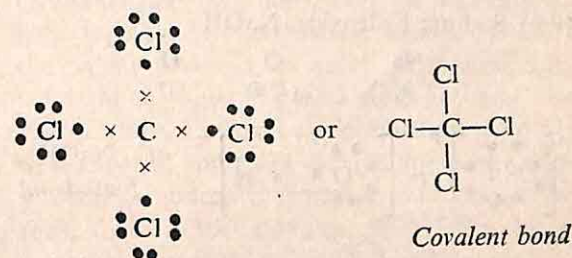
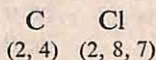
(b) Write electron dot formulae for the following ions:

Al^{+++} , S^{--} , K^+ , F^- , and B^{+++} .

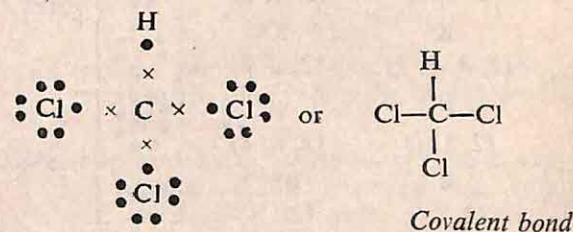
Answer: (a) (i) Magnesium chloride MgCl_2 :



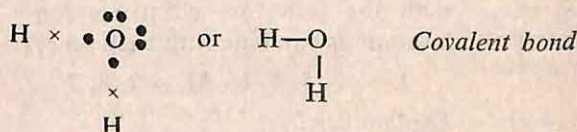
(ii) Carbon tetrachloride, CCl_4 :



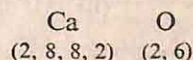
(iii) Chloroform, CHCl_3 :



(iv) Water, H_2O :



(v) Calcium oxide, CaO :



- (b) Name any three compounds formed between two atoms of the same element. Indicate the nature of bonds for the three compounds.

Answer : (a) An example of a compound formed by sharing of three pairs of electrons between two atoms is nitrogen molecule. Three bonds are formed between the two atoms. All the three bonds would be covalent. (For diagram see Q. 6.5.)

(b) O_2 (Oxygen), H_2 (Hydrogen) and F_2 (Fluorine). The bonding in these compounds is covalent.

Q. 6.13 (a) An element M gives two ionic oxides, M_2O and M_2O_2 . Answer the following questions.

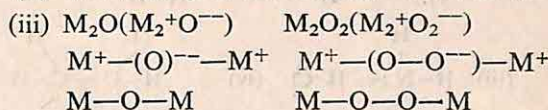
- How many electrons would be there in the outermost shell of M?
- What would be the valency of M?
- Draw the structures of the two oxides.

(b) (i) Explain briefly the terms : electrovalent bond, covalent bond and coordinate bond.

- Compare and contrast the properties usually shown by two compounds having electrovalent and covalent bonds. Also mention the difference in terms of their structure.

Answer : (a) (i) Element M will have one electron in its outermost shell.

(ii) The valency of the element M will be 1.



(b) (i) Refer to Q. 6.3, 6.5 and 6.6 (ii) For the properties refer to Q. 6.8. Ionic compounds do not possess molecules as a whole. In the crystal lattice they have cations and anions held together by electrostatic attractions. Thus the crystal becomes a single giant molecule. Covalent compounds possess molecules and not charged ions. Covalent compounds, in contrast to ionic ones, consist of definite molecules with a definite molecular formula. The molecules move freely in the gaseous phase. The inter-molecular attractions which produce solid or liquid aggregates of covalent molecules are generally much weaker.

EXERCISES

6.1 Which of the properties given below are characteristics of an ionic solid compound?

- low melting temperature,
- high boiling temperature,
- dissolves in water to form a solution containing mostly ions,
- both molten mass and aqueous solution conduct electricity,
- conducts electricity as a solid, and
- dissolves to form a solution containing mostly molecules.

(Hint : Refer to Q. 6.4)

6.2 What controls the number of electrons that an atom will lose in a reaction?

6.3 (a) Describe the electron configurations of atoms of sodium and sulphur after they have reacted to form an ionic solid.

(b) How many atoms of chlorine are required per atom of calcium to form the ionic compound calcium chloride?

6.4 (a) Indicate the nature of bonding in the following compounds : MgO , CaS , $AgNO_3$, $CuSO_4$, KBr , KI and K_2O . Give reasons.

(b) What type of bonding would you expect between the atoms of a solid substance which has a high melting point, is non-conducting when solid but conducts electricity when fused?

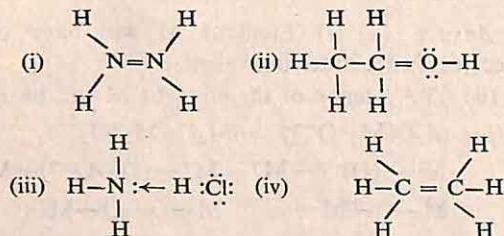
6.5 (a) The element of atomic number 17 forms one compound with the element of atomic number 12 and another compound with the element of atomic number 6.

Draw the electron dot structures of the compounds formed and name the type of bonding.

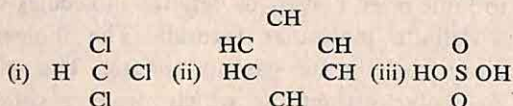
(b) Draw the electron dot structures of chlorine and potassium chloride and correlate these

with the nature of substance, i.e. one is a gas and the other a high melting point solid.

- 6.6 Which of the following electron dot structures (also known as Lewis structures) are correct? Point out the mistakes in the incorrect structures.



- 6.7 Describe as either ionic, polar or non-polar the bonds between the atoms of the compounds NaCl, ICl, CaO, Al_3N , Cs_3N , N_2 , NO and C_2H_2 .
- 6.8 Show the direction of polarity in the molecules: HCl, HBr, ClBr, NaI, BaCl_2 , H_2O and CsI.
- 6.9 From the electronic configurations of the following atoms, predict the most likely charge the ions will assume: K, Ba, P, S, F, Al and Ne.
- 6.10 Draw Lewis structures for the following compounds



- 6.11 Write the electronic configurations for Li, K, Mg, Si and Ca. Will these atoms form covalent or ionic compounds? Why?

- 6.12 Fill in the blanks using the following words: transfer, sharing, ions, polar, monatomic.

- (i) Ionic compounds are formed by the..... of electrons.
- (ii) Covalent compounds are formed by the of electrons.
- (iii) Charged atoms are.....
- (iv) Hydrogen chloride is a.....molecule.
- (v) Inert gases form.....molecules.

- 6.13 Match the descriptions under column B with terms/ statements under column A.

Column A

- Argon
- Nitrogen
- Hydrochloric acid

- Sodium chloride
- Cation
- Anion
- Sodium
- Fluorine

Column B

- has a very stable electronic structure.
 - an ionic compound.
 - an ion which carries negative charge.
 - an ion which carries positive charge.
 - a polar compound.
 - an inert gas which contains 8 electrons in the outermost shell.
 - can accept electron easily.
 - can donate electron easily.
- 6.14 Draw a line under the most appropriate answer.

- Which of the following elements can donate electrons easily?
(a) Potassium (b) Chlorine (c) Carbon (d) Sulphur.
- Which of the following illustrates the bondings in NaCl?
(a) Electron is transferred from sodium
(b) electrons are shared (c) two electrons are shared (d) electron is accepted by sodium.
- Noble gases are inactive and stable because they
(a) have low ionization energy (b) have completely filled outermost shell (c) are monatomic gases (d) have incomplete shell.
- A cation is formed
(a) by accepting an electron (b) by accepting a proton (c) by donating an electron (d) by releasing a proton.
- Which of the following compounds has a double bond?
(a) nitrogen (b) hydrogen (c) helium (d) oxygen
- Which of the following compounds has a non-polar nature?
(a) HCl (b) NaCl (c) CCl_4 (d) KCl
- Which of the following compounds involves a coordinate bond?
(a) CHCl_3 (b) H_2SO_4 (c) NH_4Cl (d) NH_3
- Which of following solutions is conducting in nature?
(a) brine solution (b) iodine solution (c) carbon tetrachloride (d) solution of H_2S in water.

UNIT 7

Periodic Classification of Elements

D. 7.1 Periodic table: It is a tabular arrangement of the elements in order of increasing atomic numbers.

D. 7.2 Periodic law: The properties of the elements are periodic function of their atomic numbers.

D. 7.3 Group: A vertical column in the periodic table is called a group.

D. 7.4 Period: A horizontal row in the periodic table is called a period.

D. 7.5 Actinides: The group of elements beginning with thorium and ending with lawrencium.

D. 7.6 Normal elements: Elements of groups IA to VIIA in the periodic table.

D. 7.7 Alkali metals: Elements of group IA in the periodic table, e.g. Li, Na, K, Rb and Cs.

D. 7.8 The alkaline earths: Elements of group IIA in the periodic table, e.g. Be, Mg, Ca, Sr and Ba.

D. 7.9 Noble gases: Elements of group zero with eight electrons in the outermost shell except helium which has only two electrons.

D. 7.10 Atomic number: Number of protons in an atom.

D. 7.11 Transition elements: These are elements of groups IB to VII B and VIII. In the atoms of these elements the outermost and some inner shells are incompletely filled with electrons.

D. 7.12 Triad: It is a group of three elements, with similar chemical properties. Dobereiner classified some elements in triads.

D. 7.13 Atomic volume: The volume occupied by one gram atom of an element in the solid state.

D. 7.14 Metals: Metals are good conductors of electricity. They tend to lose electrons to form positive ions.

D. 7.15 Non-metals: Non-metals are poor conductors of electricity. They tend to gain electrons to form negative ions.

D. 7.16 First ionization energy: It is the energy required to remove the first electron from an isolated gaseous atom.

D. 7.17 Atom electronegativity: It is the numerical measure of the attraction of bonded atom in a molecule for electrons.

D. 7.18 Law of octaves: When the elements are arranged in increasing order of atomic weight, the properties of every eighth element are similar to that of the first element.

Q. 7.1 What are Dobereiner's triads? Give examples.

Answer: In 1829, Dobereiner classified certain elements, having similar chemical properties, in groups of three, called triads. In a triad the

elements were arranged in order of increasing atomic weights. The atomic mass of the middle element was found to be approximately equal to the arithmetic mean of the other two elements. For example,

- (i)

Ca	Sr	Ba
(40)	(87)	(137)

Arithmetic mean of first and third elements
$$= \frac{40+137}{2} = 88.5$$
- (ii)

Cl	Br	I
(35.5)	(80)	(127)

$$\frac{35.5+127}{2} = 81.25$$
- (iii)

S	Se	Te
(32)	(79)	(127.5)

$$\frac{32+127.5}{2} = 79.75$$

This idea of triads could be applied to a limited number of elements known at that time.

Q. 7.2 Write a brief account of Newland's attempt towards periodic classification of elements.

Answer: In 1864, John Newland noted that when the elements were arranged in increasing

order of their atomic weight, the properties of every eighth element were similar to those of the first element, i.e. similar properties recurred at periodic intervals. Newland described this as the law of octaves. He arranged the elements known at that time in the form of a table.

Li (7)	Be (9)	B (11)	C (12)	N (14)	O (16)	F (19)
Na (23)	Mg (24)	Al (27)	Si (28)	P (37)	S (32)	Cl (35.5)
K (39)	Ca (40)					

Thus, Na, K and Li have similar properties. The law of octaves could not be applied to elements beyond calcium. The idea of octaves failed with the discovery of noble gases.

Q. 7.3 Describe in brief Lothar Meyer's classification of elements.

Answer: Lothar Meyer, in 1970, plotted a graph between atomic volume and atomic mass of the elements (Fig. 7.1). He noticed that elements with similar properties occupied

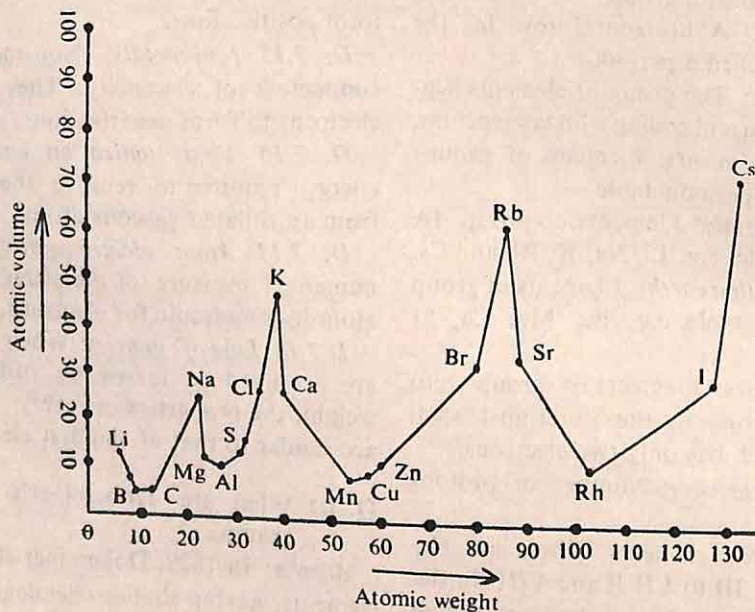


FIG. 7.1 Graph of atomic volume vs atomic mass.

similar positions on the graph. For example, the alkali metals (Li, Na, K, Rb, Cs) occupied the peak positions. Thus, Lothar Meyer observed a periodicity in the properties of the elements with atomic mass.

Q. 7.4 How is the periodic law given by Mendeleev similar to the periodic law observed by Lothar Meyer?

Answer: Lothar Meyer arrived at the periodic law by working on the physical properties of the elements such as atomic volume, melting and boiling points, volatility, fusibility, density, malleability, etc. whereas Mendeleev's periodic law was based mainly on the consideration of chemical properties of the elements. They arrived at the same conclusion working independently through different approaches.

Q. 7.5 Give a brief account of the Mendeleev's periodic classification of elements.

Answer: D.I. Mendeleev, a Russian chemist, presented in the year 1869, a classification of the elements based mainly on their chemical properties. He arranged them in horizontal rows in

such a way that elements having similar chemical properties fell directly beneath each other. This arrangement of elements is called the *periodic table*. This discovery led him to state the famous *periodic law* according to which: *the properties of elements are periodic functions of their atomic weights*. The important features of this table are :

- (i) There are nine vertical columns, called groups. Groups I to VII are sub-divided into sub-groups, A and B. Group VIII comprises transitional elements and group 0, the noble gases.
- (ii) There are seven horizontal rows, called periods. The first period is the shortest, and contains 2 elements. The second and third periods are called short periods. There contain 8 elements each. The fourth and fifth periods are called long periods containing 18 elements each. The sixth period is the longest period and contains 32 elements. The seventh period is incomplete containing the rest of the elements.

Mendeleev's periodic table is given in Fig. 7.2.

PERIOD	GROUP								
	I	II	III	IV	V	VI	VII	VIII	
	A B	A B	A B	A B	A B	A B	A B	A	
1	H								
	1.0								
2	Li	Be	B	C	N	O	F		
	6.9	9.0	10.8	12.0	14.0	16.0	19.0		
3	Na	Mg	Al	Si	P	S	Cl		
	23.0	24.3	27.0	28.1	31.0	32.1	35.5		
4	K	Ca		Ti	V	Cr	Mn	Fe	Co
	39.1	40.1		47.9	50.9	52.0	54.9	55.8	58.9
	Cu	Zn			As	Se	Br		
	63.5	65.4			74.9	79.0	79.9		
5	Rb	Sr	Y	Zr	Nb	Mo		Ru	Rh
	85.5	87.6	88.9	91.2	92.9	95.9		101.1	102.9
	Ag	Cd	In	Sn	Sb	Te	I		
	107.9	112.4	114.8	118.7	121.8	127.6	126.9		
6	Cs	Ba	La		Ta	W		Os	Ir
	132.9	137.3	138.9		180.9	183.9		190.2	192.2
	Au	Hg	Tl	Pb	Bi				
	197.0	200.6	204.4	207.2	209.0				

FIG. 7.2 Mendeleev's periodic table.

Q. 7.6 What were the advantages of Mendeleev's periodic table?

- Answer:* (i) Mendeleev's periodic table lays more stress on the similarity in the properties of the elements rather than blindly following the order of increasing atomic masses.
- (ii) The groups of elements correspond to their valencies.
 - (iii) By placing the elements strictly according to the similarity in the properties, he was also able to correct certain atomic masses.
 - (iv) Spaces left in the periodic table give an indication of the elements yet to be discovered.
 - (v) The properties of the elements yet to be discovered can be predicted even before their discoveries.
 - (vi) Mendeleev's classification condensed the study of all the elements to the study of only 9 groups.

Q. 7.7 What are the defects in Mendeleev's periodic table?

- Answer:* (i) Isotopes were not given separate places in the periodic table even though they had different atomic weights.
- (ii) The position of hydrogen was not clearly defined in the periodic table as it forms both positive and negative radicals.
 - (iii) Some chemically similar elements fall in different groups while some chemically dissimilar elements are placed together, e.g. Cu, Ag and Au are placed in the same group with alkali metals while Hg, Pb and Ba which possess similar properties, fall in different groups.
 - (iv) Certain elements of higher atomic masses are placed before certain elements of lower atomic masses, e.g. Ar (40) is placed before K (39).

Q. 7.8 What is the modern periodic law? How are the defects of the Mendeleev's table removed in the modern classification?

Answer: The defects have been removed by modifying the Mendeleev periodic law. The modern periodic law proposed by Moseley states that: *the properties of the elements are periodic function of their atomic numbers.* This removes the following defects of the Mendeleev's table.

The defect of having higher atomic mass element before the element with lower atomic mass is removed because the element having higher atomic mass has a lower atomic number in such cases. For example, the atomic number of Ar is 18 and that of K is 19.

Although isotopes of an element have different atomic masses but they have same atomic number. Hence, according to the present basis of classification, they should be allotted only one place in the periodic table.

Q 7.9 What are the general features of the long form of the periodic table?

Answer: The long form of the periodic table is sometimes referred to as the Thomson-Bohr periodic table (Fig. 7.3). This is because Thomson in the year 1885 proposed a periodic table to overcome the difficulties encountered in the Mendeleev's periodic table. This was ultimately modified by Bohr and is now known as the Thomson-Bohr periodic table. The general features of this table are:

- (i) There are 18 vertical columns called groups.
- (ii) These groups are classified into two categories; sub-group A and sub-group B.
- (iii) Sub-groups IA and IIA have elements which have partially filled or fully filled *s*-orbital as the outermost orbital. These are also called *s*-block elements.
- (iv) Sub-groups IIIA, IVA, VA, VIA, VIIA and the 'zero' group are termed as *p*-block elements. In these elements the *p*-orbital is the outermost orbital, which is being successively filled.
- (v) The sub-groups IB, IIB, IIIB, IVB, VB, VIB, VIIB and VIII contain transitional elements. These are called *d*-block elements.

GROUP	s BLOCK												p BLOCK						
	I A	II A	III B	IV B	V B	VI B	VII B	VIII		I B	II B	III A	IV A	V A	VI A	VII A	O		
PERIOD																			
1	H 1																	H 1	He 2
2	Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10	
3	Na 11	Mg 12	d BLOCK										Al 13	Si 14	P 15	S 16	Cl 17	Ar 18	
4	K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36	
5	Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54	
6	Cs 55	Ba 56	La 57	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86	
7	Fr 87	Ra 88	Ac 89	Ku 104	Ha 105														

f BLOCK

Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71
Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lw 103

FIG. 7.3 Long form of periodic table.

- In these elements the *d*-orbital (penultimate orbital) is being successively filled.
- (vi) Horizontal rows in this periodic table are called *periods*. These are in all seven periods. The number of elements in different periods are given in Fig. 7.3.
 - (vii) The zero group in the table contains elements which are called noble gases or inert gases.
 - (viii) Elements with atomic numbers 58 to 71 are called lanthanides and elements with atomic number 90 to 103 are called actinides.
 - (ix) Hydrogen has been given a place at the head of group IA as well as at the head of group VIIA. At times it is also placed at the head of group IVA. This is because

hydrogen exhibits properties similar to elements of group IA (cations) and VIIA (anions). It also forms covalent bonds with carbon.

Q. 7.10 Give the merits of the long form of the periodic table.

- Answer:** (i) The long form of the periodic table (Fig. 7.3) is based on atomic numbers which is a fundamental property of the atom.
- (ii) The anomaly regarding the position of hydrogen in Mendeleev's periodic table is removed.
 - (iii) It relates the position of an element in the periodic table with its electronic configuration.

- (iv) There is a regular gradation in properties while moving across a period or down a group.
- (v) Metals and non-metals are separated in this table.
- (vi) Typical and transitional elements have been separated in this form of the periodic table.

Q. 7.11 What are the characteristics of a group in the periodic table? Illustrate by giving suitable examples.

Answer: Elements in a group show regular gradation in physical properties and they have similar chemical properties.

- (i) Every element of the same group has the same number of valence electrons, e.g. elements of IA group have one electron in their valency shell and elements of IIA group have two electrons in their valency shell and so on.
- (ii) The size of the atom increases as we move from top to bottom in a group.
- (iii) The melting point generally decreases from top to bottom in a group.

- (iv) Metallic character increases as we move down a group.
- (v) Ionization energy decreases from top to bottom in a group.
- (vi) Electronegativity also decreases from top to bottom in a group.

Q. 7.12 Describe the regular trend in properties when we move across a period in the table.

Answer: There is a regular trend in physical and chemical properties of the elements when we move across a period in the periodic table.

- (i) The number of valence electrons increases from 1 to 8 on moving across a period from left to right.
- (ii) Atomic size decreases from left to right in a period.
- (iii) Metallic character decreases and non-metallic character increases from left to right in a period.
- (iv) Ionization energy increases from left to right in a period.
- (v) Electronegativity increases from left to right in a period.

EXERCISES

7.1 Put $\checkmark$ or $\times$ in the brackets.

- (i) The size of the atoms increases on descending a group in the periodic table. ()
- (ii) The size of the atoms increases from left to right in the periodic table. ()
- (iii) Li and Mg have similar properties because of the diagonal relationship. ()
- (iv) In the periodic table, horizontal rows are called groups and vertical columns are called periods. ()
- (v) The ionization energy increases as we move from top to bottom in a group in the periodic table. ()
- (vi) Electronegativity increases as we move from left to right in a period in the periodic table. ()
- (vii) Chemical properties of the elements are periodic function of their valence electrons. ()
- (viii) Metallic character increases from top to bottom in a group.

7.2 Give the terms used to express the following.

- (a) Vertical columns in a periodic table.
- (b) Horizontal rows in a periodic table.
- (c) Elements having the same atomic number.
- (d) Elements which have both acidic and basic nature.
- (e) Elements with complete outer shell.

7.3 Match the descriptions under column B against the terms/statements under column A.

Column A

- (i) Mendeleev
- (ii) Dobereiner
- (iii) Isotopes
- (iv) Isobars
- (v) Period
- (vi) Group

Column B

- (i) proposed the triad law.
- (ii) elements with same atomic number.

- (iii) vertical columns in a periodic table.
- (iv) horizontal rows in a periodic table.
- (v) elements with different atomic number but same atomic mass.
- (vi) presented a classification of the elements on the basis of chemical properties.

7.4 Underline the most appropriate answer.

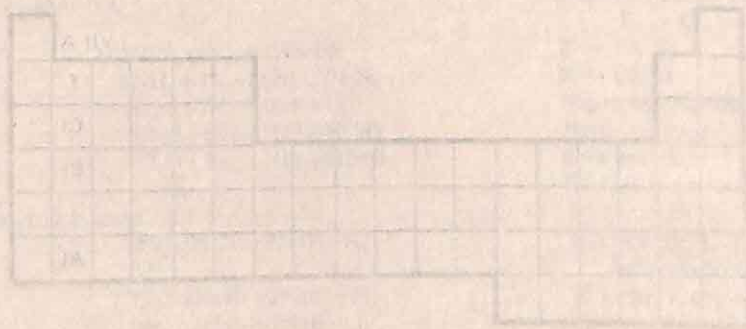
- (i) Which of the following pairs belong to the same period?
(a) Na and K (b) B and C (c) F and Cl (d) Mg and Ca.
- (ii) Which of the following pairs of elements have structural similarity?
(a) O and P (b) B and Al (c) F and Ne (d) Ba and C.
- (iii) Which of the following elements is the most electropositive?
(a) F (b) A (c) K (d) Cu.
- (iv) The modern periodic table is based upon
(a) chemical properties (b) atomic masses
(c) atomic number (d) atomic volume.
- (v) Which of the following electronic configurations represents chlorine?
(a) 2, 8, 1 (b) 2, 7 (c) 2, 8, 8, 7 (d) 2, 8, 7
- (vi) Which of the following sets of elements belong to the halogen family?
(a) Cl, Br and I (b) Li, Ne and K (c) He, Ne and A (d) Ca, Sr and Ba.
- (vii) The law of octaves was proposed by
(a) Lothar Meyer (b) Newlands (c) Dobereiner (d) Moseley.

7.5 Fill in the blanks.

- (i) All the elements in a group in the periodic table have same.....

- (ii) The of the periodic table is based on atomic numbers.
- (iii) According to the modern form of periodic law, the properties of elements are periodic function of their
- (iv) In the long form of the periodic table, there are vertical columns, ... groups and periods.
- (v) element has the highest electron affinity.

- 7.6 Write a brief account of Dobereiner's and Newland's attempts in the classification of elements.
- 7.7 Write a short note on the periodic law.
- 7.8 What are the main features of the periodic table? Discuss its importance.
- 7.9 Describe anomalies of Mendeleev's classification. How have they been overcome in the present basis of the periodic classification of elements?
- 7.10 Describe the general features of the long form of periodic table.
- 7.11 Discuss various horizontal, vertical and diagonal relations in the periodic table.
- 7.12 Define (i) a group and (ii) a period.
- 7.13 Why is there a need to classify the elements.
- 7.14 Write the group number for each of the following elements: Na, Be, C, O, Cl.
- 7.15 Discuss the gradation of properties of typical elements in groups IA and IIA.
- 7.16 Comment on the statement 'the properties of the elements are periodic functions of their atomic numbers'.
- 7.17 How does the size of the atom vary in the periodic table? Explain.
- 7.18 Write short notes on: (i) Electron affinity (ii) Ionization energy (iii) Electronegativity.



The Halogens

variety of chemical reactions. Some of these are summarised in Table 8.2.

All hydrohalides are soluble in water and produce aqueous solutions known as hydrofluoric, hydrochloric, hydrobromic and hydroiodic acids. HF is a weak acid whereas HCl, HBr and HI are among the strongest acids known.

Q. 8.1 What are halogens?

Answer: The elements of group VIIA of the periodic table, fluorine (F), Chlorine (Cl), bromine (Br), iodine (I) and astatine (At) are called *halogens*. The name is derived from the Greek word 'halos' which means 'sea salt former'. In sea water, these are found as chlorides, bromides and iodides of sodium and magnesium.

Amongst the halogens, fluorine is the most hazardous. Their chemical properties are very similar and show a regular gradation in the order $F_2 > Cl_2 > Br_2 > I_2$. They undergo a

[illegible]

FIG. 8.1

TABLE 8.1 PHYSICAL CHARACTERISTICS OF GROUP VIIA ELEMENTS

Characteristic	Fluorine	Chlorine	Bromine	Iodine
Symbol	F	Cl	Br	I
Atomic number	9	17	35	53
Electronic arrangement	2, 7	2, 8, 7	2, 8, 18, 7	2, 8, 18, 18, 7
Valency	1	1	1	1
Physical state	gas	gas	liquid	solid
Colour	pale yellow	greenish yellow	reddish brown	steel grey
Melting point (K)	53	172	266	387
Boiling point (K)	86	238.4	331.7	457
Density (g/cm ³)	1.1	1.5	3.2	4.9

TABLE 8.2 SOME CHEMICAL PROPERTIES OF HALOGENS

Sl. No.	Reaction with	Reaction equation	Remarks/Conditions
1	METALS		
	(a) Active metals (Na, Mg)	$2\text{Na} + \text{X}_2 \rightarrow 2\text{NaX}$ $\text{Mg} + \text{X}_2 \rightarrow \text{MgX}_2$	} X = F, Cl, Br, I
	(b) Less active metals (Fe, Al)	$2\text{Fe} + 3\text{X}_2 \rightarrow 2\text{FeX}_3$ $2\text{Al} + 3\text{X}_2 \rightarrow 2\text{AlX}_3$	
2	NON-METALS (P)	$\text{P}_4 + 6\text{X}_2 \rightarrow 4\text{PX}_3$ $\text{P}_4 + 10\text{Cl}_2 \rightarrow 4\text{PCl}_5$	} X = F, Br, I
3	HYDROGEN	$\text{H}_2 + \text{F}_2 \rightarrow 2\text{HF}$ $\text{H}_2 + \text{Cl}_2 \rightarrow 2\text{HCl}$ $\text{H}_2 + \text{Br}_2 \rightleftharpoons 2\text{HBr}$ $\text{H}_2 + \text{I}_2 \rightleftharpoons 2\text{HI}$	Reaction explosive even at low temp. and in dark. Reaction slow in dark. Fast in sunlight. Reaction only in presence of Pt catalyst at 473 K. Reaction incomplete even in presence of Pt catalyst.
4	ALKALI (NaOH)	$2\text{NaOH} + \text{X}_2 \rightarrow \text{NaX} + \text{NaOX} + \text{H}_2\text{O}$ (cold dil.) $6\text{NaOH} + 3\text{X}_2 \rightarrow \text{NaXO}_3 + 5\text{NaX} + 3\text{H}_2\text{O}$ (hot conc.) $2\text{NaOH} + \text{F}_2 \rightarrow 2\text{NaF} + \text{OF}_2 + \text{H}_2\text{O}$ (cold dil.) $4\text{NaOH} + 2\text{F}_2 \rightarrow 4\text{NaF} + \text{O}_2 + \text{H}_2\text{O}$ (hot conc.)	} X = Cl, Br, I
5	OXIDIZING CHARACTER		
	(a) H_2S	$\text{H}_2\text{S} + \text{X}_2 (\text{aq.}) \rightarrow 2\text{HX} + \text{S}$	Oxidizing action decreases in the order $\text{F}_2 > \text{Cl}_2 > \text{Br}_2 > \text{I}_2$ X = Cl, Br, I. X = Cl, Br Vigorous reaction. Rapid reaction. Slow reaction. No reaction with I_2
	(b) NH_3	$8\text{NH}_3 + 3\text{X}_2 \rightarrow 6\text{NH}_4\text{X} + \text{N}_2$	
	(c) H_2O	$2\text{H}_2\text{O} + 2\text{F}_2 \rightarrow 4\text{HF} + \text{O}_2$ $\text{H}_2\text{O} + \text{Cl}_2 \rightarrow \text{HCl} + \text{HClO}$ $\text{H}_2\text{O} + \text{Br}_2 \rightarrow \text{HBr} + \text{HBrO}$	
6	DISPLACEMENT REACTIONS	$\text{F}_2 + 2\text{NaX} \rightarrow 2\text{NaF} + \text{X}_2$ $\text{Cl}_2 + 2\text{NaX} \rightarrow 2\text{NaCl} + \text{X}_2$ $\text{Br}_2 + 2\text{NaI} \rightarrow 2\text{NaBr} + \text{I}_2$	

Q. 8.2 In what forms do the halogens occur in nature?

Answer: Halogens do not occur free in nature due to their strong chemical reactivity. They exist in the combined states. Relative abundance of the halogens in nature is given in Table 8.3.

TABLE 8.3 ABUNDANCE OF HALOGENS IN NATURE

Element	Abundance in earth's crust (per cent)	Abundance in sea water (per cent)
F	0.06–0.09	.002
Cl	0.0314	1.5
Br	1.6×10^{-4}	0.015
I	3×10^{-5}	0.001

Fluorine is found in the widely distributed mineral fluorite (CaF_2). Cryolite (Na_3AlF_6) and fluorapatite [$3\text{Ca}_3(\text{PO}_4)_2 \cdot \text{CaF}_2$] are also sources of fluorine.

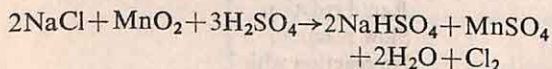
Chlorine is the most abundant halogen in nature. Sodium chloride, present in sea water, is the richest source of chlorine. Chlorine is also present in the form of magnesium chloride in sea water. Deposits of sodium chloride also occur on land and are known as rock salt.

Bromine is found as soluble bromides (NaBr , KBr , MgBr) in sea water. It is also found in salt mines as sodium bromide.

Sea weeds are the richest source of iodine. Iodine in a combined form is found in sea water, and also as sodium iodate (NaIO_3) in sodium nitrate deposits.

Q. 8.3 State the methods for the preparation of halogens.

Answer: Chlorine, bromine and iodine are prepared by the oxidation of halide ions with a strong oxidizing agent.



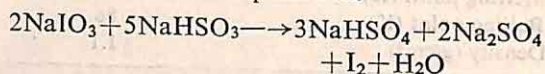
For the preparation of Br_2 and I_2 , KBr and KI are used respectively. A mixture of the halide and powdered MnO_2 is heated with H_2SO_4 .

Chlorine is produced commercially from sodium chloride by electrolysis of the molten

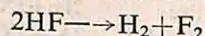
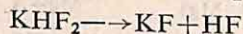
salt or by electrolysis of brine. To get bromine on a commercial scale, sea water is first acidified and then saturated with Cl_2 to effect the reaction



Iodine is produced commercially from sodium nitrate deposits (chile saltpeter) in which small quantities of NaIO_3 are found. Iodate ion solution is reduced with sulphite ion.



Usual methods of oxidizing halide ions are not used for the preparation of fluorine as there is no other substance that can oxidize fluoride ions to fluorine. Fluorine is prepared by electrolysis of molten mixture of KHF_2 and HF .



Q. 8.4 Halogen molecules are more soluble in carbon tetrachloride than in water. Explain.

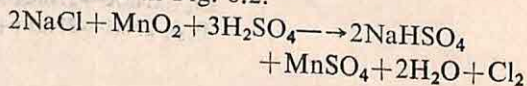
Answer: Each halogen is one electron short of the stable configuration of the nearest noble gas. They form molecules, i.e. F_2 , Cl_2 , Br_2 and I_2 through a single covalent bond. These halogen molecules are non-polar. Carbon tetrachloride is non-polar whereas water is polar. Polar solutes are more soluble in polar solvents and vice-versa. Therefore, halogen molecules are more soluble in carbon tetrachloride than in water.

Q. 8.5 Give the laboratory preparation, properties and uses of chlorine.

Answer

PREPARATION

Chlorine is prepared by heating a mixture of manganese dioxide (MnO_2) and sodium chloride (NaCl) with concentrated sulphuric acid (H_2SO_4). Being heavier than air it is collected by upward displacement of air. The arrangement is shown in Fig. 8.2.



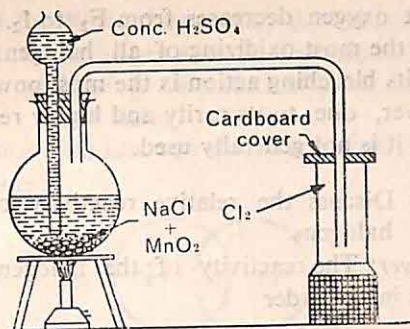


FIG. 8.2 Preparation of chlorine.

PHYSICAL PROPERTIES

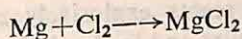
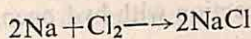
Chlorine is a greenish-yellow gas, heavier than air, having a strong pungent smell. It is poisonous.

Chlorine is soluble in water in the ratio 1:3 at room temperature. The aqueous solution is pale green in colour and is known as chlorine water.

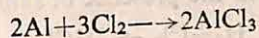
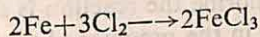
On liquefaction it gives a yellow liquid with a boiling point of 238.4 K and a melting point of 172 K.

CHEMICAL PROPERTIES

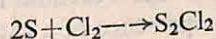
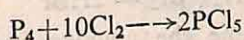
1. *Reaction with metals*: Active metals like sodium and magnesium form electrovalent chlorides when the burning metal is introduced in chlorine.



Less active metals such as iron and aluminium on heating with chlorine form covalent chlorides.

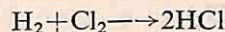


2. *Reaction with non-metals*: Non-metals such as phosphorous, sulphur, etc. react with chlorine to form chlorides.



3. *Affinity for hydrogen*: Chlorine has a great

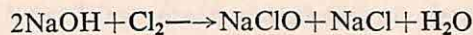
affinity for hydrogen. In the presence of sunlight, chlorine reacts with hydrogen.



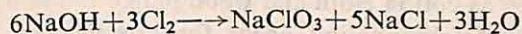
A burning taper dipped in turpentine oil ($\text{C}_{10}\text{H}_{16}$) gives out black smoke of carbon, and HCl is produced.



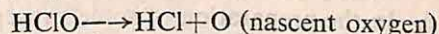
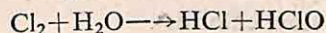
4. *Reaction with alkali (NaOH)*: When chlorine is bubbled through a solution of cold dilute sodium hydroxide a solution containing sodium hypochlorite (NaClO) is obtained.



On bubbling chlorine through a hot concentrated sodium hydroxide solution, sodium chlorate (NaClO_3) is formed.



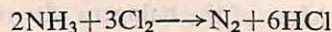
5. *Oxidizing character*: Chlorine acts as an oxidizing agent as it reacts with water to form hypochlorous acid which decomposes to give nascent oxygen.



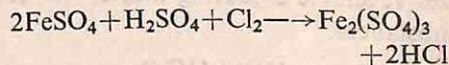
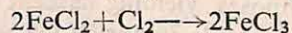
(a) Hydrogen sulphide is oxidized by chlorine to sulphur.



(b) Chlorine removes hydrogen from ammonia to give nitrogen.



(c) Chlorine oxidizes iron (II) chloride and acidified iron (II) sulphate to iron (III) chloride and iron (III) sulphate respectively.



(d) Chlorine, in the presence of water, is a powerful bleaching agent. The bleaching action is due to its oxidizing properties. The nascent oxygen liberated when chlorine is dissolved in water reacts with vegetable colouring matter to give a colourless compound.

6. *Reaction with slaked lime:* Chlorine reacts with slaked lime (Ca(OH)_2) giving bleaching powder (CaOCl_2).



7. *Halogen displacement reactions:* Chlorine is more reactive than bromine or iodine. It therefore liberates bromine and iodine from solutions of bromide and iodide respectively.



USES

1. In the sterilization of drinking water and water in swimming pools.
2. As a bleaching agent for substances such as cotton cloth and wood pulp.
3. As chlorinating agent for organic compounds.
4. In the manufacture of bleaching powder, dye stuffs, explosives, etc.
5. In the preparation of some useful plastics (e.g., polyvinyl chloride).
6. In the preparation of some antiseptics and insecticides (e.g. benzene hexachloride and DDT).

Q. 8.6 Explain the bleaching action of halogens. Are all the halogens capable of acting as bleaching agents? Explain.

Answer: Most of the halogens (fluorine, chlorine, bromine, iodine) act as oxidizing agents. Cl_2 and Br_2 oxidize water giving hypochlorous acid (HClO). The hypochlorous acid thus obtained decomposes yielding nascent oxygen which oxidizes vegetable colouring matter to colourless substances.



Bleaching action of bromine is slow. Iodine does not bleach. This is because the chemical reactivity of halogens decreases from top to bottom in the periodic table, i.e. $\text{F}_2 > \text{Cl}_2 > \text{Br}_2 > \text{I}_2$. The reactivity with water to liberate

nascent oxygen decreases from F_2 to I_2 . Fluorine is the most oxidizing of all halogens and hence its bleaching action is the most powerful. However, due to its rarity and highly reactive nature it is not generally used.

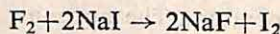
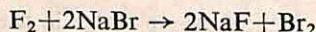
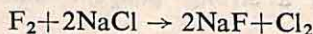
Q. 8.7 Discuss the relative reactivity of the halogens.

Answer: The reactivity of the halogens decreases in the order

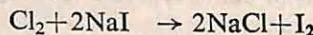


The relative reactivity is supported by the following displacement reactions.

- (i) Fluorine being the most active can displace all other halogens from their halides.



- (ii) Chlorine displaces all halogens except fluorine.



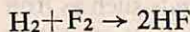
- (iii) Bromine can displace only iodine.



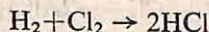
- (iv) Iodine cannot displace any of the halogens and is the least reactive.

The gradation in their reactivity can also be seen in their reaction with hydrogen.

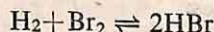
- (i) Fluorine reacts explosively even at low temperature and in the dark.



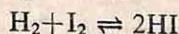
- (ii) With chlorine the reaction is slow in dark and fast in the presence of sunlight.



- (iii) Bromine reacts with hydrogen only in the presence of platinum catalyst at 473 K.

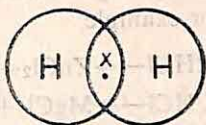


- (iv) With iodine the reaction is incomplete even in the presence of a catalyst.

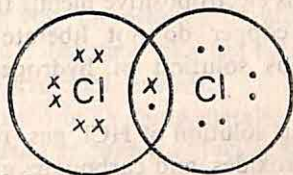


- Q. 8.8 (a) Write the electron dot structures of hydrogen and chlorine molecules.
 (b) What is the nature of bond in these molecules?

Answer: (a) Electron dot structure of hydrogen molecule is



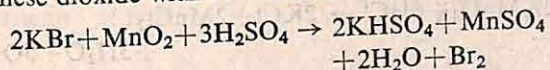
Electron dot structure of chlorine molecule is



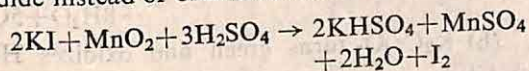
(b) The bonds in these molecules are covalent as one electron from each atom is being shared.

- Q. 8.9 How will you prepare bromine and iodine? Give their important uses.

Answer: Bromine can be prepared by heating a mixture of potassium bromide and manganese dioxide with concentrated sulphuric acid.



Iodine can be prepared by using potassium iodide instead of bromide as above.



Uses of bromine: 1. Bromides are used in medicines as sedatives.

2. AgBr is used in making photographic paper and films.

3. Bromine is used in the manufacture of dyes.

Uses of iodine: 1. In the manufacture of dyes and pharmaceutical chemicals.

2. In volumetric estimations.

3. In medicines (tincture of iodine and iodoform are used as antiseptics).

4. AgI is used in making photographic paper and films.

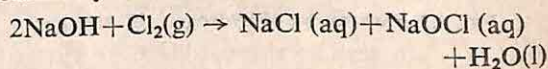
- Q. 8.10 What are the methods of detecting chlorine, bromine and iodine.

Answer: Halogens can be detected by their physical properties of smell, colour and state (however as they are poisonous, smelling them is usually avoided), as well as by their action on starch iodide paper and carbon disulphide. The scheme for detection is outlined in Table 8.4.

- Q. 8.11 Name any two bleaching materials. Give their preparation. State the uses of one of them.

Answer: Sodium hypochlorite (NaOCl) and bleaching powder (CaOCl₂) are important bleaching materials.

Preparation: Sodium hypochlorite solution is prepared by passing chlorine gas through sodium hydroxide solution.



Bleaching powder is prepared by passing chlorine gas through slaked lime.

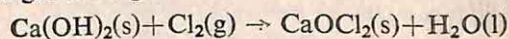


TABLE 8.4 DETECTION OF HALOGENS

Property	Chlorine	Bromine	Iodine
State and colour	Greenish-yellow gas	Reddish-brown liquid	Steel grey solid
Smell	Pungent	Pungent	Pungent
Action on starch iodide paper	Turns starch iodide paper blue	Turns starch iodide paper blue	Turns starch iodide paper violet or deep blue
Action on carbon disulphide		Dissolves giving orange-coloured solution	Dissolves giving violet solution

Uses of bleaching powder: 1. In bleaching cotton, wood pulp, etc.

2. In making wool shrink resistant.

3. For disinfecting lavatories, drains, etc.

4. For disinfecting water.

5. For the manufacture of chloroform and some aniline dyes.

Q. 8.12 Describe the preparation and properties of hydrogen chloride gas. Mention the uses of hydrogen chloride and hydrochloric acid.

Answer:

PREPARATION

In the laboratory hydrogen chloride gas is prepared by heating sodium chloride with concentrated sulphuric acid (Fig. 8.3).

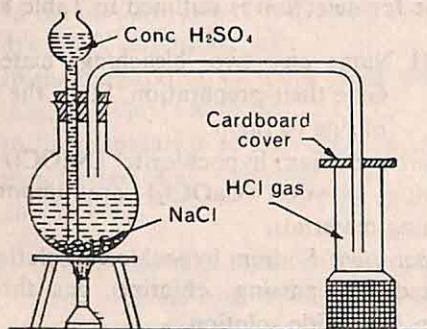


FIG. 8.3 Preparation of hydrogen chloride gas.

The gas is collected by upward displacement of air.

PROPERTIES

1. Colourless poisonous gas with pungent smell.

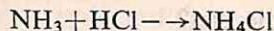
2. Highly soluble in water.

3. Neither combustible nor a supporter of combustion.

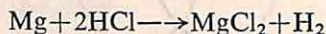
4. Heavier than air.

5. Aqueous solution of hydrogen chloride gas turns blue litmus red, and hence is acidic. This solution is known as hydrochloric acid.

6. *Reaction with ammonia:* HCl gas gives white fumes both with NH_3 gas and NH_4OH forming NH_4Cl .

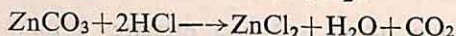
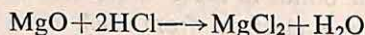


7. More electropositive metals than hydrogen liberate hydrogen with aqueous solution of HCl. For example,



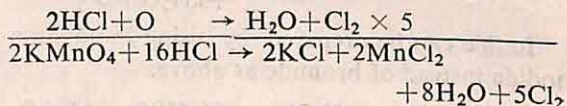
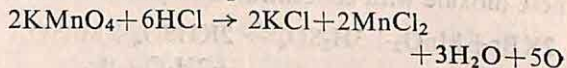
Aluminium and iron react with HCl in a similar way. Less electropositive metals than hydrogen such as copper do not liberate hydrogen from aqueous solution of hydrogen chloride gas.

8. Aqueous solution of HCl gas reacts with oxides, hydroxides and carbonates giving chlorides and water.

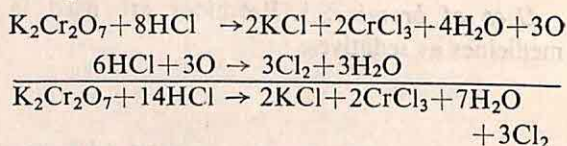


9. *Reducing properties:* HCl is oxidized to Cl_2 in the presence of strong oxidizing agents.

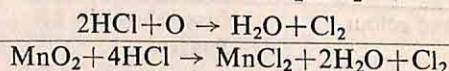
(a) KMnO_4 solution becomes colourless and oxidizes HCl to Cl_2 .



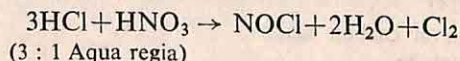
(b) $\text{K}_2\text{Cr}_2\text{O}_7$ turns green and oxidizes HCl to Cl_2 .



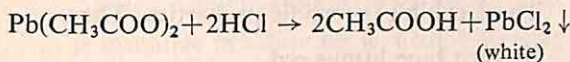
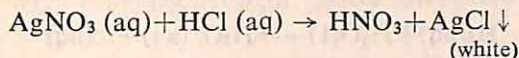
(c) MnO_2 oxidizes HCl to Cl_2 .



(d) Concentrated HNO_3 oxidizes HCl to Cl_2 .



10. *Precipitation reactions:* HCl acid forms precipitates with salt solutions of silver, lead, etc.



USES

(i) Hydrochloric acid is used for the preparation of various chlorides. It is also used for the purification of common salt.

(ii) It is a very important laboratory reagent.

(iii) It is a constituent of aqua regia, which is used to dissolve noble metals.

(iv) It is used in cleaning metals.

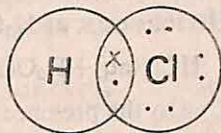
(v) It is used to prepare glucose from starch.

Q. 8.13 (a) Write the electron dot structures of HCl, HBr, and HI.

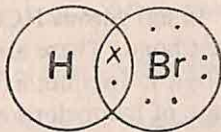
(b) Classify the following halides as soluble or insoluble in water.

(i) NaCl (ii) AgCl (iii) KBr (iv) AgBr
(v) KI and (vi) AgI.

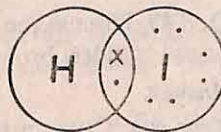
Answer: Electron dot structure of HCl.



Electron dot structure of HBr.



Electron dot structure of HI.



Soluble

NaCl
KBr
KI

Insoluble

AgCl
AgBr
AgI

Q. 8.14 Draw a neat labelled diagram of the apparatus used for showing in the laboratory that hydrogen chloride gas

is very soluble in water and the solution formed is acidic. Explain how you would carry out the experiment.

Answer

FOUNTAIN EXPERIMENT

Fill a round bottomed flask with hydrogen chloride gas. Take water containing some blue litmus in a beaker and set the apparatus as shown in Fig. 8.4. On pressing the rubber teat of the dropper filled with water, the water enters the flask and dissolves some HCl gas. This reduces the pressure in the flask and consequently litmus solution is sucked into the flask. More hydrogen chloride gas dissolves and the coloured solution rises up and forms a fountain in the flask. The blue colour of the solution changes to red. This shows that hydrogen chloride gas is highly soluble in water and its solution is acidic in nature.

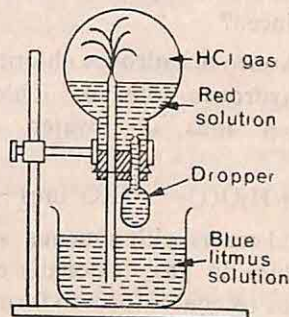


FIG. 8.4 The fountain experiment.

Q. 8.15 Describe how you would prepare a concentrated solution of hydrochloric acid in the laboratory.

Answer: Concentrated HCl solution contains about 36% by weight of HCl gas. The HCl gas is generally prepared by heating NaCl with concentrated H_2SO_4 . The gas is highly soluble in water. The solution cannot be prepared by simply passing HCl gas through a tube into water as water would flow back into the HCl. Hence a device to prevent sucking back is used as shown in Fig. 8.5. The big opening of the funnel must be fixed under the water. When water

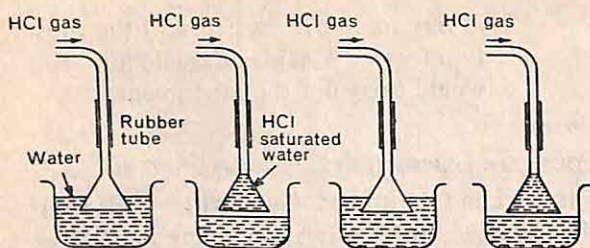


FIG. 8.5 Arrangement to prevent sucking back in the preparation of hydrochloric acid.

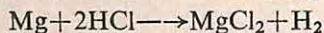
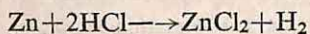
begins to suck back, the level of the water in the beaker becomes lower, and the edge of the funnel is exposed. Air then enters the funnel and all the liquid falls back into the beaker. The process is repeated until a saturated solution is obtained.

Q. 8.16 When an aqueous solution of hydrogen chloride gas reacts with a metal which element in the molecule is reduced?

Answer : Aqueous hydrogen chloride dissociates to give hydrogen ions and chloride ions. The hydrogen ions in water exist as $\text{H}_3\text{O}^+(\text{aq})$.



When a metal reacts with aqueous solution of hydrogen chloride gas, it donates electrons to hydrogen ions to enable them to form hydrogen.

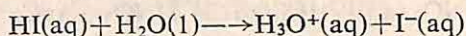
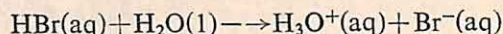


Thus, the element hydrogen in the molecule is reduced.

Q. 8.17 Aqueous solutions of hydrogen halides are called hydrochloric, hydrobromic and hydroiodic acids. How do they dissociate in aqueous solutions? In what form do H^+ ions exist in aqueous solutions? Do these exhibit acidic properties?

Answer: Hydrochloric, hydrobromic and hydroiodic acids dissociate to give H^+ and halide

ions. The H^+ ions in water exist as $\text{H}_3\text{O}^+(\text{aq})$.



These exhibit the acidic properties. They,

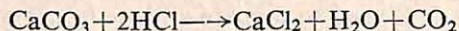
- turn blue litmus red,
- react with some metals with the evolution of hydrogen,



- neutralize alkalis,

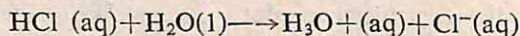


- decompose carbonates and bicarbonates with the evolution of carbon dioxide.



Q.8.18 Compare and contrast the chemical activity of anhydrous HCl with that of hydrochloric acid.

Answer: Hydrogen chloride gas in water is called hydrochloric acid. In hydrochloric acid, H^+ ions exist as $\text{H}_3\text{O}^+(\text{aq})$.



Due to the presence of $\text{H}_3\text{O}^+(\text{aq})$ ions, hydrochloric acid exhibits all acidic properties.

In anhydrous HCl there is a single polar covalent bond. There are no H_3O^+ , H^+ or Cl^- ions. Thus, it does not exhibit acidic properties as in case of hydrochloric acid.

Q. 8.19 Discuss the chemistry of tests for chlorides, bromides and iodides.

Answer

TEST FOR CHLORIDE

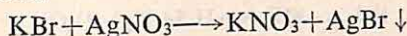
When silver nitrate is added to an aqueous solution of a metal chloride, a white precipitate of silver chloride, is formed. For example,



The precipitate is insoluble in dilute nitric acid but dissolves in ammonium hydroxide.

TEST FOR BROMIDE

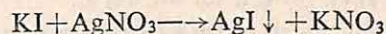
Add silver nitrate to an aqueous solution of a metal bromide. A light yellow precipitate is produced.



This is insoluble in dilute nitric acid but sparingly soluble in ammonium hydroxide.

TEST FOR IODIDE

When silver nitrate solution is added to an aqueous solution of a metal iodide, a yellow precipitate of silver iodide is formed.



The precipitate is insoluble in both dilute nitric acid and ammonium hydroxide.

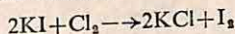
EXERCISES

- 8.1 Arrange the halogens in order of increasing (i) atomic radius (ii) boiling point (iii) oxidizing activity and (iv) intensity of colour.
- 8.2 From each of the following sets point out the required substance.

- | | |
|----------------------------------|--------------|
| (i) Largest atom : | F, Cl, Br, I |
| (ii) Strongest oxidizing agent : | F, Cl, Br, I |
| (iii) Most electro-positive : | F, Cl, Br, I |
| (iv) Strongest bleaching agent : | F, Cl, Br, I |

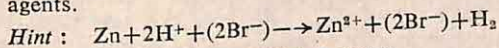
- 8.3 Which of the following statements concerning the element chlorine are correct?

- (i) Chlorine is in the group VIIA of the periodic table.
- (ii) Chlorine is in the 3rd period of the periodic table.
- (iii) Chlorine is more active than iodine as evidenced by the reaction

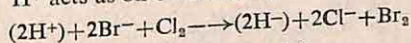


- (iv) Chlorine is a halogen.
- (v) One mole of chlorine contains 2g atoms.
- (vi) Chlorine has seven electrons in its outermost shell.
- (vii) Chlorine is more soluble in non-polar solvents than in water.
- (viii) Chlorine is a better oxidizing agent than Bromine.

- 8.4 Show by chemical equations that H^+ and Br^+ ions of aqueous HBr act as oxidizing and reducing agents.



H^+ acts as an oxidizing agent.



Br^- acts as a reducing agent.]

- 8.5 Match the descriptions under column B against the statements/terms under column A.

COLUMN A

- (i) Aqua regia
(ii) Cryolite

- (iii) Silver bromide
(iv) Silver chloride
(v) Chlorine
(vi) Bromine

COLUMN B

- (i) Used in photography.
- (ii) A greenish yellow gas.
- (iii) A mixture of concentrated nitric acid and hydrochloric acid in the ratio of 1 : 3.
- (iv) A brown liquid.
- (v) A source of fluorine.
- (vi) Soluble in ammonia.
- 8.6 Underline the most appropriate answer.
- (i) Which of the following compounds is used in the preparation of chlorine.
(a) NaCl (b) $\text{K}_2\text{Cr}_2\text{O}_7$ (c) HNO_3 (d) HCl .
- (ii) The bleaching action of chlorine depends upon
(a) oxidation (b) reduction (c) chlorination (d) hydrogenation.
- (iii) Which of the following silver halides is most soluble in ammonia.
(a) AgF (b) AgCl (c) AgBr (d) AgI .
- (iv) Chlorine gas forms white fumes with
(a) hydrochloric acid (b) ammonia (c) water (d) any substance.
- (v) Halogens are generally prepared from halides by
(a) Electrolytic and chemical oxidation methods.
(b) Electrolytic and chemical reduction methods.
(c) Chemical oxidation.
(d) Chemical reduction.
- (vi) Which of the following substance is used for bleaching purposes.
(a) sodium chloride (b) sodium hydrochloride (c) sodium hydroxide (d) sodium bromide.

(vii) Which of the following halogens is the most basic?

(a) F_2 , (b) Cl_2 , (c) Br_2 , (d) I_2 .

(viii) Which of the following halogens is the most abundant in the earth's crust

(a) F_2 , (b) Cl_2 , (c) Br_2 , (d) I_2 .

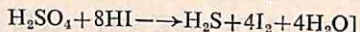
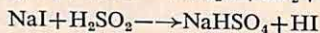
8.7 Illustrate the general group trends by the members of group VIIA with regard to three physical properties and three chemical properties.

(Hint : *Physical Properties* : colour, intensity, m.p. and density. *Chemical Properties* : oxidizing action, reaction with water and action with metals.)

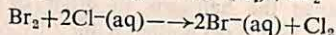
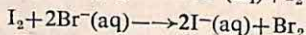
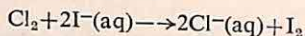
8.8 Why cannot pure HBr and HI be prepared by the action of concentrated H_2SO_4 upon metal bromides and iodides respectively? Give the equations involved.

[Hint : In their preparation undesirable products are obtained. HBr and HI produced in this way

reduce H_2SO_4 to SO_2 and H_2S respectively. HI is a stronger reducing agent than HBr.]



8.9 Which of the following reactions will occur as given? Formulate a generalization about which halogens will displace others from an aqueous solution of the halide ions.



8.10 Why are the halogens not found free in nature?

8.11 How do halogens react with NaOH solution?

8.12 Do halogens acquire noble gas configurations during compound formation? Comment.

UNIT 9

Oxygen and Sulphur

Both oxygen and sulphur belong to group VIA of the periodic table (Fig. 9.1). Some of the physical characteristics of oxygen and sulphur are summarized in Table 9.1.

FIG. 9.1

TABLE 9.1 IMPORTANT PHYSICAL PROPERTIES OF
OXYGEN AND SULPHUR

	Oxygen	Sulphur
Symbol	O	S
Atomic number	8	16
Electronic structure	2, 6	2, 8, 6
Physical state	Gas	Solid
Melting point (K)	54.6	385.8, 392.3
Boiling point (K)	90	717.6

Oxygen, the most abundant element on the earth, is found in the atmosphere in the form of diatomic molecules, O_2 . It also exists in the

combined state in water and in the soil and rocks of the crust of the earth.

Elemental oxygen is a colourless and odourless gas which is needed by animals for life process. It is a typical non-metal. The electron configuration of oxygen is $1s^2, 2s^2, 2p^4$, with two of the $2p$ electrons unpaired. It shows allotropy. Its other molecular form is ozone, O_3 . Atmospheric O_3 plays a vital role in maintaining life on earth because of the ability of O_3 molecules to absorb ultraviolet radiation.

Oxygen combines with most of the other elements to form numerous compounds. With metals it forms ionic compounds and with non-metals, covalent compounds. Oxides of the non-metals react with water to form oxyacids.

The most important compound of oxygen is water, H_2O . Some of the chemical properties of oxygen are listed in Table 9.2. Both ordinary oxygen and ozone are good oxidizing agents.

Sulphur is found extensively in the earth's crust both in the free elemental state and in the combined state. Sulphur is a brittle, yellow, solid non-metal. Similar to oxygen, it has six electrons in the outermost orbit with two of the $3p$ electrons unpaired.

Sulphur displays allotropy to a remarkable degree, existing in a variety of different molecu-

TABLE 9.2 CHEMICAL PROPERTIES OF OXYGEN

S. No.	Reaction with	Reaction equation	Remarks
1	METALS		
(a)	noble metals : Au, Pt	—	Immune to attack by O ₂
(b)	reactive metal : Na	$4\text{Na} + \text{O}_2 \rightarrow 2\text{Na}_2\text{O}$	Na burns in O ₂
(c)	less reactive metals : Cu, Mg	$\left. \begin{aligned} 2\text{Cu} + \text{O}_2 &\rightarrow 2\text{CuO} \\ 2\text{Mg} + \text{O}_2 &\rightarrow 2\text{MgO} \end{aligned} \right\}$	Slow reaction on heating
2	NON-METALS		
(a)	C	$\left. \begin{aligned} 2\text{C} + \text{O}_2 &\rightarrow 2\text{CO} \\ \text{C} + \text{O}_2 &\rightarrow \text{CO}_2 \end{aligned} \right\}$	With limited O ₂ With excess O ₂
(b)	P, S	$\left. \begin{aligned} \text{P}_4 + 5\text{O}_2 &\rightarrow \text{P}_4\text{O}_{10} \\ \text{S} + \text{O}_2 &\rightarrow \text{SO}_2 \end{aligned} \right\}$	P and S burn rapidly when heated in O ₂
(c)	H ₂	$2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$	
3	COMPOUNDS		
(a)	CH ₄	$\text{CH}_4 + \text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$	
(b)	BaO, NO, SO ₂	$\begin{aligned} 2\text{BaO} + \text{O}_2 &\rightarrow 2\text{BaO}_2 \\ 2\text{NO} + \text{O}_2 &\rightarrow 2\text{NO}_2 \end{aligned}$	
		$\begin{array}{c} \text{Pt catalyst} \\ 2\text{SO}_2 + \text{O}_2 \rightarrow 2\text{SO}_3 \\ \text{heat} \end{array}$	
(c)	CS ₂ , ZnS, H ₂ S	$\begin{aligned} \text{CS}_2 + 3\text{O}_2 &\rightarrow \text{CO}_2 + 2\text{SO}_2 \\ 2\text{ZnS} + 3\text{O}_2 &\rightarrow 2\text{ZnO} + 2\text{SO}_2 \\ 2\text{H}_2\text{S} + 3\text{O}_2 &\rightarrow 2\text{H}_2\text{O} + 2\text{SO}_2 \end{aligned}$	
(d)	HCl	$\begin{array}{c} \text{CuCl}_2 \\ 4\text{HCl} + \text{O}_2 \rightarrow 2\text{H}_2\text{O} + 2\text{Cl}_2 \\ \text{catalyst} \end{array}$	
(e)	Organic compounds		
	C ₂ H ₅ OH	$\text{C}_2\text{H}_5\text{OH} + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O}$	
	C ₁₂ H ₂₂ O ₁₁ (sugar)	$\text{C}_{12}\text{H}_{22}\text{O}_{11} + 12\text{O}_2 \rightarrow 12\text{CO}_2 + 11\text{H}_2\text{O}$	

lar and physical forms. In the solid state, sulphur occurs in the form of S₈ molecules.

Sulphur is a necessary element in a technological society, where it appears as sulphuric acid. The consumption of H₂SO₄ is often regarded as a measure of industrialization of a country. Oxides (SO₂, SO₃) hydrides (H₂S), oxyacids (H₂SO₃, H₂SO₄) and sulphides (CS₂) are some of the important compounds of sulphur.

Some of the important chemical properties of sulphur are listed in Table 9.3.

Based on periodic relationships and electron configurations, a similarity exists between sulphur and oxygen compounds. Both elements form

binary ionic compounds with active metals and both form a number of similar compounds, such as CO₂ and CS₂.

- Q. 9.1 (a) Infer from the electronic configurations of oxygen and sulphur about the position of these two elements in the periodic table.
- (b) Name the other two elements belonging to the same group.
- (c) State the different ways in which both oxygen and sulphur acquire a stable electronic configuration.

TABLE 9.3 CHEMICAL PROPERTIES OF SULPHUR

S. No.	Reaction with	Reaction equation	Remarks
1	METALS : Fe, Mg, Zn, Al, Cu	$\text{Fe} + \text{S} \rightarrow \text{FeS}$ $\text{Mg} + \text{S} \rightarrow \text{MgS}$ $\text{Zn} + \text{S} \rightarrow \text{ZnS}$ $2\text{Al} + 3\text{S} \rightarrow \text{Al}_2\text{S}_3$ $\text{Cu} + \text{S} \rightarrow \text{CuS}$	
2	NON-METALS : F_2 , Cl_2 , O_2 , C, H_2	$3\text{F}_2 + \text{S} \rightarrow \text{SF}_6$ $2\text{Cl}_2 + \text{S} \rightarrow \text{SCl}_4$ $\text{O}_2 + \text{S} \rightarrow \text{SO}_2$ $\text{C} + 2\text{S} \rightarrow \text{CS}_2$ $\text{H}_2 + \text{S} \rightarrow \text{H}_2\text{S}$	
3	OXIDIZING ACIDS : HNO_3 , H_2SO_4	$6\text{HNO}_3 + \text{S} \rightarrow 2\text{H}_2\text{O} + \text{H}_2\text{SO}_4 + 6\text{NO}_2$ $2\text{H}_2\text{SO}_4 + \text{S} \rightarrow 2\text{H}_2\text{O} + 3\text{SO}_2$	
4	ALKALIES : NaOH (hot conc.)	$6\text{NaOH} + 3\text{S} \rightarrow 2\text{Na}_2\text{S} + \text{Na}_2\text{SO}_3 + 3\text{H}_2\text{O}$	

Answer (a) The electronic configuration of oxygen and sulphur is as follows :

Oxygen (8) = 2, 6

Sulphur (16) = 2, 8, 6

There are six electrons in the outermost shell of both oxygen and sulphur. Since these determine the position in the periodic table, both oxygen and sulphur belong to group VIA of the periodic table.

(b) Selenium and tellurium.

(c) Atoms of both oxygen and sulphur are two electrons short of the stable electronic configuration of the next noble gas, viz., neon and argon respectively. Completion of the octet in the valence shell of oxygen and sulphur is achieved by (i) forming the dinegative ion O^{2-} and S^{2-} by accepting two electrons; (ii) exercising a covalency of two, i.e. forming a double bond with other atoms by sharing two of its electrons with two electrons of another atom.

Q. 9.2 (a) State the forms in which oxygen and sulphur exist in nature.

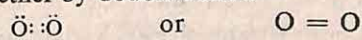
(b) Discuss the structure of oxygen and sulphur molecules.

Answer (a) Oxygen occurs in the native state in the atmosphere as diatomic molecules, $\text{O}_2(\text{g})$, forming about one fifth of the atmosphere by

weight. It also exists in the combined state mainly as oxides (e.g. SiO_2), as nitrates (e.g. NaNO_3) and carbonates (e.g. CaCO_3) etc. Water is a big source of oxygen.

Sulphur is widely spread in nature. It occurs mainly as sulphides (FeS , PbS , etc.) and sulphates (CaSO_4 , MgSO_4 etc.) of metals. It is also present in various forms in plants and animals. It is present in onion, garlic, mustard, egg, protein, oils, etc. It also occurs in the free state in Japan, Italy, and USA (Texas and Louisiana).

(b) Oxygen exists in the form of discrete molecules. Two oxygen atoms are joined together by double bonds.



The atoms of sulphur usually do not show multiple bonding like oxygen. Sulphur in the solid state exists as S_8 which has the following structure, known as the puckered ring structure (Fig. 9.2). Oxygen is a gas and sulphur is a

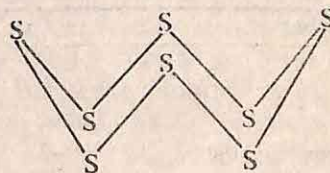


FIG. 9.2 The puckered ring structure.

solid. This difference in their state is due to their atomicity. Oxygen has two atoms in its molecule (O_2) while sulphur has eight atoms (S_8).

Q. 9.3 What are the various constituents of the atmosphere? Comment on the presence of oxygen and its role in the atmosphere.

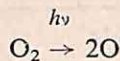
Answer: The atmosphere is the mantle of gases which surrounds and envelops the earth. The atmosphere is a mixture of gases, the most abundant of which are nitrogen and oxygen (Table 9.1). The percentage of carbon dioxide in the air varies somewhat and that of dust and water vapour is widely variable. There are also traces of inert gases, hydrogen, ammonia, hydrogen sulphide, oxides of nitrogen, sulphur dioxide and other gases. The average composition of dry air at sea level is given in Table 9.4.

Atmospheric oxygen is continuously consumed by combustion and respiration processes. But the oxygen content of the atmosphere remains almost constant as the oxygen is continuously reproduced by the plants by the photosynthesis process. Oxygen being heavier than nitrogen, the amount of oxygen in the atmosphere decreases with increasing altitude. This is why mountaineers face difficulty in breathing on high mountains. They, therefore, carry oxygen cylinders with them.

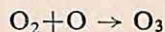
Atmospheric oxygen contains the three isotopes of oxygen: $^{16}_8O$, $^{17}_8O$ and $^{18}_8O$.

At high altitudes (stratosphere, i.e. the region of the atmosphere extending from the surface of the earth to an altitude of about 20 km)

ultraviolet light from the sun, dissociates some O_2 into atoms.



These atoms are captured by other O_2 molecules forming ozone (O_3), an allotrope of O_2 .



Ozone helps in preserving life on the earth by absorbing much of the harmful ultraviolet rays in sunlight.

Q. 9.4 Discuss briefly the Frasch method for the extraction of sulphur.

Answer: Sulphur is found in the free state in underground deposits especially in the USA. Since the layers lie more than 800 feet below the surface of the earth, under layers of quicksand and gravel, this makes its direct mining impossible. It is extracted by the Frasch method. Three concentric pipes are sunk into the ground to reach the deposits (Fig. 9.3). Super heated water is forced down the outer pipe and compressed air is blown down the central shaft (innermost pipe). The molten sulphur at the base of the pipes forms a froth with the compressed air and rises to the surface through the middle pipe. It is then allowed to cool and solidify. This sulphur is of about 99.9% purity.

Q. 9.5 (a) State the difference between polymorphism and allotropy.

(b) Describe briefly the various allotropic forms of oxygen and solid sulphur.

TABLE 9.4 COMPOSITION OF DRY AIR

Component	% by volume	% by weight
Nitrogen	78.03	75.51
Oxygen	20.99	23.15
Inert gases (mainly Argon)	0.96	1.28
Carbon dioxide	0.03–0.04	0.046
Hydrogen	0.01	0.0000035

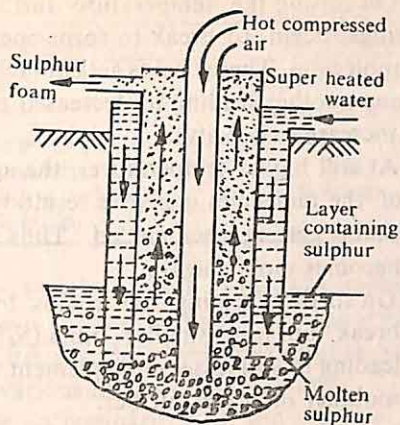


FIG. 9.3 Extraction of sulphur by the Frasch method.

Answer: (a) When a substance exists in more than one form in the same physical state the phenomenon is called polymorphism. Polymorphism in an element is called allotropy. The term allotropy is restricted only to elements and covers all the states (liquid, solid, gas) of the elements. Polymorphism is a general term. It includes elements and other substances, such as molecular compounds, etc., only in the crystalline state.

(b) Both oxygen and sulphur exhibit the property of allotropy. Oxygen has two allotropes, i.e. oxygen (O_2) and ozone (O_3). Sulphur exists in a variety of forms. Solid sulphur exists in three distinct forms, i.e., rhombic (α -sulphur), monoclinic (β -sulphur) and amorphous or plastic (γ -sulphur).

O_2 is the usual and most abundant form of oxygen. Ozone may be obtained by passage of an electric discharge through oxygen at a low pressure. It exists as triatomic molecules.

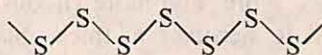


Ozone is present in the atmosphere at high altitudes. It is formed by the action of ultraviolet rays on O_2 .

At ordinary temperature the stable allotrope of sulphur is the *rhombic form*, but above 368.6K the *monoclinic form* is more stable. 368.6 K is known as the transition temperature.

However, interconversion between the two forms is slow. Both contain S_8 puckered rings (see Fig. 9.2). Both are soluble in non-polar solvents such as benzene and carbon disulphide, ether and alcohol.

A third unstable allotrope is called *plastic sulphur*. This is an amorphous solid derived from a supercooled liquid. It does not contain molecular rings but long helical chains of sulphur atoms. The long chains are of variable



length. It is insoluble in nonpolar solvents. At ordinary temperature the long chains slowly disintegrate and re-form the small S_8 rings, which crystallize gradually in rhombic lattice.

Q. 9.6(a) Starting from ordinary roll sulphur describe how you would prepare samples of: (i) rhombic sulphur, (ii) monoclinic sulphur, and (iii) plastic sulphur.

(b) Describe the effect of heat on sulphur.

Answer: (i) Rhombic sulphur is the main constituent of roll sulphur.

A solution of roll sulphur is prepared in carbon disulphide. The solution is filtered to remove the impurities. Rhombic sulphur separates from the filtrate on slow evaporation as octahedral crystals. It melts at 385.8K.

(ii) Monoclinic form of sulphur crystallizes from hot molten sulphur above 368.6 K as long prismatic needles.

A small amount of roll sulphur is melted in a porcelain dish. The melt of sulphur is allowed to cool slowly. A solid crust is formed over the surface. Two small holes are made in the crust and any remaining molten sulphur is poured out. Long needle shaped crystals of monoclinic sulphur are left behind in the dish. It melts at 391.2K. Monoclinic sulphur can also be obtained by crystallizing sulphur from hot toluene.

(iii) Plastic sulphur is obtained as an amber-brown soft and sticky elastic solid by pouring boiling sulphur in a slow stream into cold water.

(b) Crushed roll sulphur on heating undergoes the following changes:

- Its colour changes to orange-brown and it melts at 387 K to an amber-yellow mobile liquid.
- On raising the temperature further it becomes more and more viscous. At about 453 K it becomes a thick, black liquid which does not flow out even if the tube is inverted.
- At still higher temperatures, the thick dark mass begins to become mobile and its colour also becomes lighter.
- At its boiling point (717K) it becomes a mobile liquid and starts boiling, giving intense red vapours having the formula S_8 .
- The red vapours (S_8) on further heating dissociate into S_4 and S_2 and finally to S at 2300 K. These changes are reversed on cooling the vapours of sulphur.

These observations can be explained as follows (Fig. 9.4):

- (a) A molecule of sulphur consists of rings of 8 atoms (S_8) (Fig. 9.4). On melting, these rings can easily slip over one another and hence molten sulphur is initially mobile.

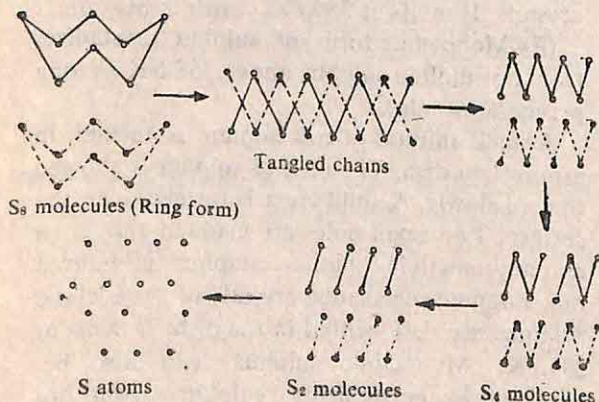


FIG. 9.4 Effect of heat on sulphur.

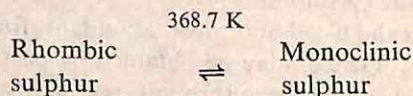
- On raising the temperature further, the rings begin to break to form open chain molecules. These chains get entangled with one another leading to decreased mobility (increased viscosity).
- At still higher temperatures, the agitation of the molecules increases resulting in the chains getting disentangled. Thus sulphur becomes mobile again.
- On further heating the chains begin to break up into smaller units (S_4 and S_2) leading to still lesser entanglement and the mobility increases further.

Q. 9.7(a) State which of the three allotropes of sulphur is most stable.

- At what temperature does monoclinic sulphur change into rhombic sulphur and vice versa. Do the crystals of monoclinic sulphur lose their identity during transition?
- Under what circumstances does plastic sulphur change into rhombic sulphur.
- State the atomicity acquired by the three allotropes.

Answer: (a) Rhombic sulphur is the most stable.

(b) Below 368.6 K, monoclinic sulphur slowly changes into rhombic sulphur. Above 368.6 K rhombic sulphur reverts to monoclinic sulphur. Thus, 368.6 K is the transition temperature between the two forms.



The amber yellow crystals of monoclinic sulphur, if left for several days, change over into rhombic sulphur. Each crystal retains its overall shape but changes into a mass of small rhombic crystals.

- Plastic sulphur slowly changes over into rhombic sulphur on long standing.
- Both rhombic and monoclinic sulphur consist of S_8 molecules in the puckered ring

TABLE 9.4 PHYSICAL PROPERTIES OF ALLOTROPES OF SULPHUR

Property	Rhombic	Monoclinic	Plastic
Colour	Pale yellow	Yellow	Yellowish-brown
State	Octahedral crystals	Needle-like crystals	Rubber-like mass
Melting point	387.5	392	No definite m.p.
Specific gravity	2.06	1.98	1.95
Solubility in carbon disulphide	Soluble	Soluble	Insoluble

structure. Plastic sulphur consists of completely random arrangement of chains of sulphur atoms.

Q. 9.8 Compare the physical properties of the various allotropes of sulphur.

Answer: A comparison of the physical properties of the allotropes of sulphur is given in Table 9.4.

Q. 9.9 How can you prove that the allotropic forms of sulphur consist of sulphur only.

Answer: The following observations prove that all allotropic forms of sulphur consists of sulphur only.

- All the forms can be interconverted by altering only the physical conditions.
- Equal weight of each allotrope can be burnt to form the same weight of sulphur dioxide.
- Vapours of all allotropes give rhombic sulphur on cooling.

Q. 9.10 State some of the physical properties of oxygen and sulphur. Also give a brief account of some of their chemical reactions.

Answer: Oxygen is a colourless gas, slightly soluble in water. It liquefies at 90 K to a pale blue liquid and freezes at 54 K to a blue solid. It is slightly heavier than air.

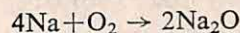
Sulphur is a pale yellow solid with no odour. It is a non-conductor of heat and electricity. It has very low solubility in water.

REACTIONS OF OXYGEN

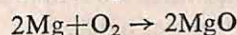
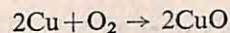
Chemically oxygen is very reactive, combining

either directly or indirectly with many metals, non-metals and a large number of compounds.

Reaction with metals: Noble metals such as gold, platinum, etc. are immune to attack by oxygen. Sodium burns in oxygen giving the oxide.

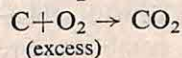
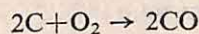


With lead it reacts spontaneously. With other less electropositive metals such as copper, magnesium and mercury it combines slowly on heating.

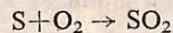
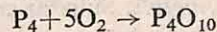


Reaction with non-metals: All non-metals except the halogens, noble gases and nitrogen burn in oxygen.

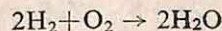
It reacts with carbon at high temperatures to form carbon monoxide or carbon dioxide.



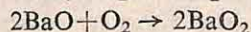
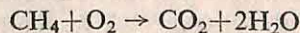
Sulphur and phosphorus burn rapidly if heated in the presence of oxygen.



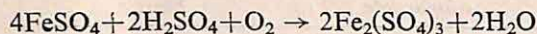
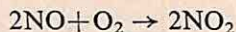
Oxygen reacts readily with hydrogen to form water.



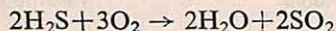
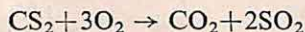
Reaction with compounds: In its reaction with compounds it either combines with the elements or with the compound as a whole, e.g.



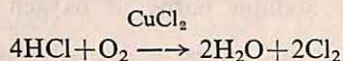
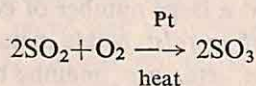
In many cases it acts as an oxidizing agent, e.g.



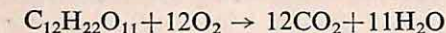
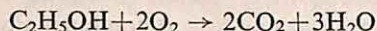
Carbon disulphide and hydrogen sulphide burn if ignited in oxygen.



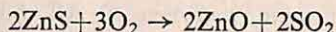
Oxygen oxidizes some compounds in the presence of a catalyst, e.g.



Organic compounds form carbon dioxide and steam with oxygen.



Metallic sulphides when roasted in air form sulphur dioxide and metal oxide.

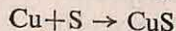
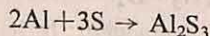
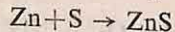
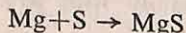
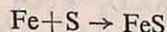


(This type of reaction is useful in the extraction of metals. Zn is isolated by reducing zinc oxide obtained by roasting naturally occurring ZnS.)

REACTIONS OF SULPHUR

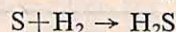
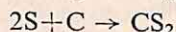
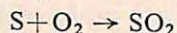
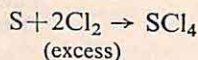
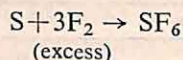
Sulphur burns in air with a blue flame to form the dioxide. It combines directly with most metals when heated, non-metals and compounds.

Reaction with metals: Sulphur combines with many metals giving sulphides.

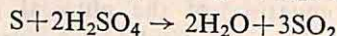
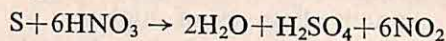


Reaction with non-metals: Various non-metals that react with sulphur include fluorine, chlorine, bromine, hydrogen, oxygen, carbon, phos-

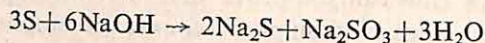
phorus, etc. It reacts less readily with non-metals than oxygen.



Reaction with acids: Sulphur is inert to aqueous hydrochloric acid but is attacked by oxidizing acids.



Reaction with alkalis: With hot concentrated solutions of alkalis, sulphides and sulphites are produced.

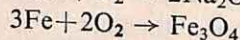
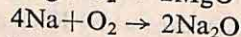
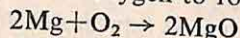


Q.9.11 Write a short note on combustion.

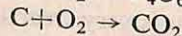
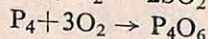
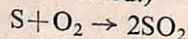
Answer: The most characteristic and well-known chemical reaction of oxygen is combustion. It involves the evolution of great quantity of heat and the generation of a flame. The flame produced by burning a substance in pure oxygen is much brighter and hotter than produced in air as the atmospheric oxygen is diluted by nitrogen and the other gases.

Wax, coal, coke, charcoal, wood, kerosene oil, petrol, domestic gas, glucose, sucrose, etc. undergo combustion when ignited in air or oxygen.

Oxygen is a very active element and supports combustion of several metals and non-metals. These combine with oxygen to form oxides.

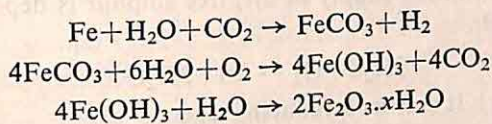


(Iron, heated to red heat, burns giving a shower of sparks in the presence of oxygen. Molten beads of Fe_3O_4 are formed.)



Q.9.12 What do you understand by the rusting of iron? Give the mechanism of rusting and the possible ways of preventing it.

Answer: Rusting of iron is the most common type of corrosion. When iron is exposed to atmospheric conditions (moist air, CO_2 etc.) it is covered with a loose brown coating called rust. Rust is a hydrated form of ferric oxide, $\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$ or $\text{FeO}(\text{OH})$. The oxide is non-sticking in nature and peels off exposing more of iron surface for further rusting. The chemical changes in rust formation appear to be as follows:



Iron articles are susceptible to corrosion because their surface is both chemically reactive and heterogeneous. This is so because more oxygen gets accumulated in troughs, cavities or on the bent parts compared to smooth surfaces.

Rusting can be prevented in a number of ways. The iron articles are first cleaned and then covered with a layer of metal more electropositive than iron, e.g. zinc. The process of covering iron with zinc is called galvanization. Zinc is acted upon by air and moisture and a protective film of ZnCO_3 . $\text{Zn}(\text{OH})_2$ is formed, which prevents further corrosion. A protective film of Zn, Mg or Al powder mixed with paint can also be applied.

An impenetrable (barrier) film of an oil, grease, a paint or another metal, like chromium, tin, nickel and copper help in preventing rusting. However, the scratches or cracks developed in the barrier film may initiate the process of rusting which spreads below the film.

Iron articles dipped into alkaline phosphate or chromate solutions can also be protected from rusting. These anti-rust solutions tend to deposit an insoluble protective film on the iron surface, and thus save it from being rusted.

Q.9.13 State the various uses of oxygen.

Answer: Most of the uses of commercial oxygen are based upon the property that the element acts as an oxidizing agent. Some of the important uses are listed below.

1. As 'tonnage' oxygen in steel making.
2. In the manufacture of nitric acid, methyl alcohol, ethylene oxide and other chemicals.
3. As a propelling fuel in rockets, satellites, missiles, etc. in the form of liquid oxygen.
4. In oxy-acetylene torches for the high temperature welding and cutting of metals.
5. In bleaching and in thickening of oils used in making varnishes, linoleum, etc.
6. In making explosive cartridges by mixing it with carbon dust to be used in coal mining in place of dynamite.
7. It is essential for normal respiration, in breathing equipments for mountaineers, air-men, divers, etc.
8. Vital for combustion processes.
9. Used for medicinal purposes for artificial respiration, etc.

Q.9.14 (a) Name the hydrides of oxygen and sulphur.

(b) How will you prepare the hydrides of oxygen and sulphur directly from the constituent elements?

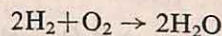
Answer: (a) The hydrides of oxygen and sulphur are water and hydrogen sulphide respectively.

Water : H_2O

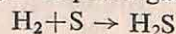
Hydrogen sulphide : H_2S

Hydrogen peroxide (H_2O_2) is another known hydride of oxygen.

(b) By igniting a mixture of oxygen and hydrogen, water is obtained. Hydrogen burns in oxygen and water drops are formed on the walls of the container.



Hydrogen sulphide can be prepared by the direct union of hydrogen and sulphur. On passing hydrogen gas through a boiling solution of sulphur, hydrogen sulphide gas is formed.



Q.9.15 How will you prepare hydrogen sulphide from iron sulphide? Describe the physical and chemical properties of hydrogen sulphide.

Answer: Hydrogen sulphide can be prepared by the action of dilute sulphuric acid on iron sulphide.

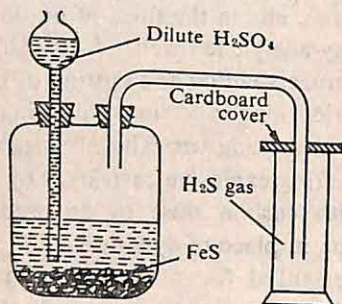
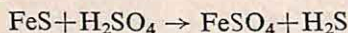


FIG. 9.5 Preparation of hydrogen sulphide gas.

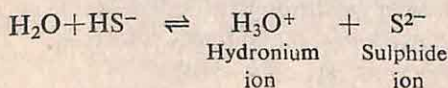
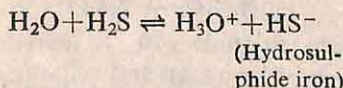
Iron sulphide is placed in a Woulfe's bottle fitted with a thistle funnel and delivery tube. Dilute H_2SO_4 or HCl is poured through the thistle funnel. The gas is collected by upward displacement of air. It cannot be collected over water as it is soluble in it.

PHYSICAL PROPERTIES

Hydrogen sulphide is a colourless gas having the unpleasant smell of rotten eggs and is poisonous. It is heavier than air and soluble in water. It is not a supporter of combustion but itself burns in air. Its boiling point is 213K and melting point is 189K.

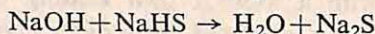
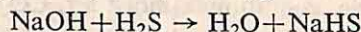
CHEMICAL PROPERTIES

(i) Hydrogen sulphide is a very weak dibasic acid in aqueous solution. Ionization in water takes place in two stages:

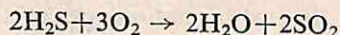


Hydronium ion (H_3O^+) is responsible for the acidic nature of the aqueous solution of H_2S .

(ii) On reacting with bases it gives two types of salts, the normal sulphides (M_2S , MS) and hydrosulphides (MHS , $\text{M}(\text{HS})_2$).



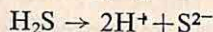
(iii) H_2S burns in a plentiful supply of air with a pale blue flame forming sulphur dioxide and water.



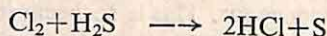
In a limited supply of air, free sulphur is deposited.



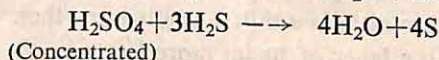
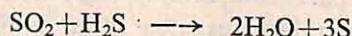
(v) It acts as a reducing agent.



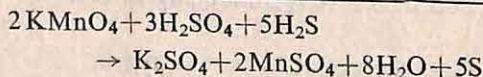
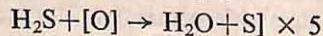
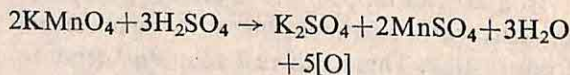
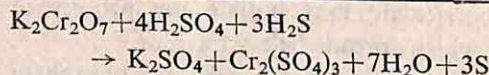
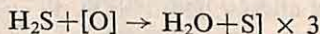
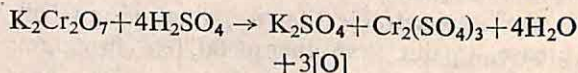
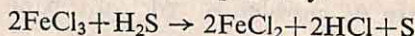
Moisture



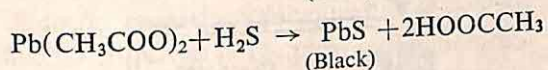
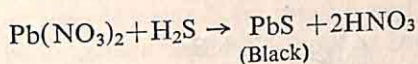
Moisture



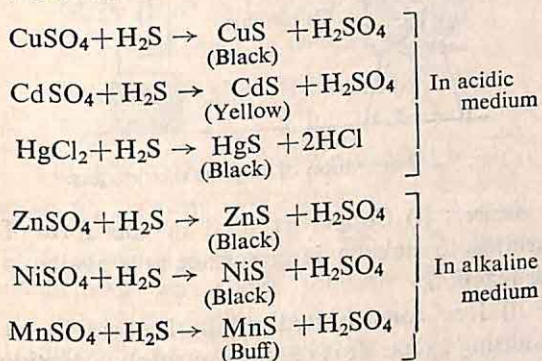
It will reduce ferric salt, permanganates and dichromates to ferrous, manganese (II) and chromium (III) salts, respectively.



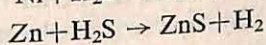
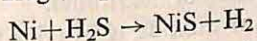
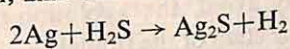
(v) It reacts with many salt solutions forming insoluble coloured sulphides. Some sulphides are precipitated in acidic medium and some others are precipitated in alkaline medium. When a strip of filter paper dipped into a solution of lead acetate or lead nitrate is exposed to the vapours of H_2S , it turns black due to the formation of lead sulphide (PbS).



In a similar fashion, H_2S reacts with other metal salt solutions.



(vi) Hydrogen sulphide reacts with metals like silver, nickel, zinc and tin to liberate hydrogen.



Q. 9.16 Compare and contrast the properties of the hydrides of oxygen and sulphur.

Answer: Points of resemblance : The hydrides of both oxygen (H_2O) and sulphur (H_2S) are polar in nature and have similar chemical constitution.

Points of difference : 1. Water is a liquid while hydrogen sulphide is a gas at room temperature.

2. H_2S is a colourless gas with the smell of rotten eggs. Water is odourless.

3. Water is neutral, i.e. neither acidic nor basic. It has no effect in litmus. On the other hand the aqueous solution of H_2S acts as a weak acid which turns blue litmus red.

4. H_2S burns in a plentiful supply of air with a pale blue flame forming SO_2 and water while water does not burn.

5. H_2S forms salts with alkalies while water does not react with alkalies.

6. H_2S reacts with lead acetate solution to give lead sulphide (black colour) while no marked change is observed with water.

7. H_2S acts as a reducing agent while water does not act as a reducing agent.

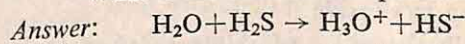
Q. 9.17 (a) H_2S on dissolving in water gets ionized in two steps. Give the chemical equations corresponding to the ionization stages.

(b) What would be the behaviour of this solution towards litmus.

(c) Copper sulphate solution reacts with this to give a coloured precipitate. State whether the medium is alkaline or acidic.

(d) Which two types of salts are possible?

What is the basis of this possibility?



(b) Solution will turn blue litmus red.

(c) Acidic.

(d) On the basis of ionization of aqueous solutions of H_2S two types of salts, the normal sulphides (M_2S , MS) and hydrosulphides (MHS , $\text{M}(\text{HS})_2$) are formed.

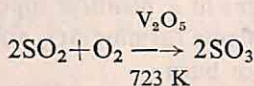
Q. 9.18 (a) Name the two oxides of sulphur.

(b) Give outlines for preparing sulphuric acid from the oxide of sulphur.

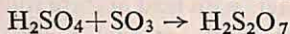
Answer: (a) Sulphur forms two oxides, viz., sulphur dioxide (SO_2), and sulphur trioxide (SO_3).

(b) In the first step, SO_2 is prepared by burning sulphur in air. After drying and purifying,

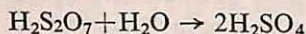
SO₂ and excess air are passed over platinized asbestos or vanadium pentoxide at a temperature of about 723K and at atmospheric pressure.



Sulphur trioxide is dissolved in concentrated sulphuric acid to form oleum (H₂S₂O₇).



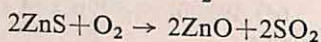
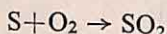
This is then diluted with a calculated amount of water to give sulphuric acid.



Q. 9.19 Describe three methods for the preparation of sulphur dioxide gas. Draw a neat labelled diagram of the apparatus used for the preparation of SO₂ in the laboratory.

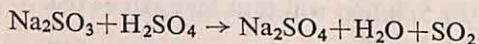
Answer: Sulphur dioxide can be prepared in the following ways:

1. By burning of sulphur or a metal sulphide in air or oxygen.



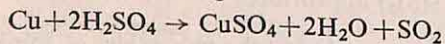
The burning of sulphur is employed to prepare SO₂ on large scale.

2. By the action of dilute sulphuric acid on a metal sulphite.



This method can be used in the laboratory also.

3. Sulphur dioxide is generally prepared in the laboratory by heating concentrated sulphuric acid with copper turnings.



The gas is collected in a gas jar by upward displacement of air (Fig. 9.6).

In place of a round bottom flask, a hard boiling tube can also be used.

Q. 9.20 In the preparation of sulphur dioxide by heating copper turnings with sulphuric acid the following are used:

(i) Copper is used in the form of turnings.

(ii) Concentrated sulphuric acid is used.

(iii) Thistle funnel is always kept dipped into the solution.

(iv) The gas receiver (jar) is always kept with its mouth up.

Give reasons.

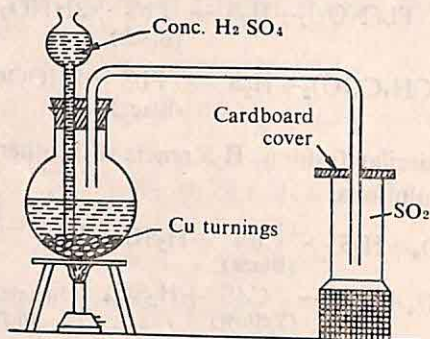


FIG. 9.6 Preparation of sulphur dioxide gas.

Answer: (i) Copper is used in the form of turnings to make a large surface area available for reaction.

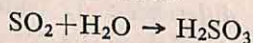
(ii) Hot concentrated sulphuric acid is an oxidising agent. It is reduced to sulphur dioxide when heated with copper.

(iii) The thistle funnel is always kept under solution to avoid the evolution of gas formed through the stem of the funnel.

(iv) Sulphur dioxide is heavier than air and is collected by upward displacement of air. Hence, the mouth of the gas receiver is kept facing up.

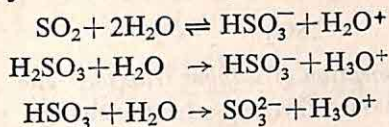
Q. 9.21 Give the various properties of sulphur dioxide.

Answer: Sulphur dioxide is a colourless gas with a sharp, choking smell of burnt sulphur. It is highly soluble in water.



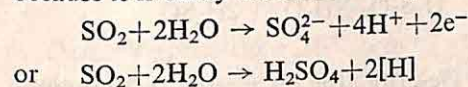
Its aqueous solution is acidic and acts as a reducing agent. The acid so produced acts *in situ* and has never been isolated. The acid,

sulphurous acid (H_2SO_3) is dibasic in nature. H_2SO_3 ionizes to form hydronium ions.

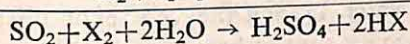
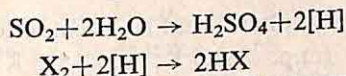


It is poisonous in nature. Its inhalation causes inflammation of the lungs and other disorders. It is more than twice as dense as air and can readily be liquefied. Liquid SO_2 boils at 264 K.

Reducing properties: Sulphur dioxide exhibits reducing properties in the presence of moisture because it is easily oxidized to sulphuric acid.

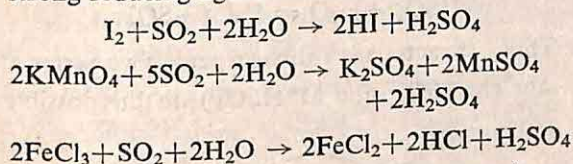


It reduces halogens to halogen acids.

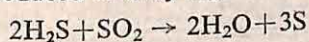
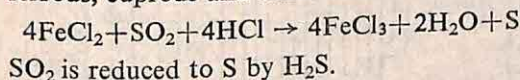


where $\text{X} = \text{Cl}, \text{Br}, \text{or I}$.

An aqueous solution of SO_2 decolourizes iodine and an acidic solution of KMnO_4 , and reduces ferric salts to ferrous. It acts as a strong reducing agent in alkaline solution.

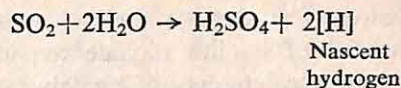


Oxidizing properties: In certain reactions, SO_2 can act as an oxidizing agent. For example, metals such as iron, magnesium, etc. burn in SO_2 to give mixed sulphides and oxides. In very strong acidic solution SO_2 can oxidize ferrous, cuprous and other ions.



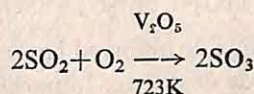
Bleaching action: SO_2 possesses weak bleaching properties in the presence of moisture. The bleaching action is due to the reduction of the colours of substances by nascent hydrogen

which is formed when SO_2 reacts with water. Hence, it only bleaches moist materials.



Its bleaching action is mild. Hence, it is used for delicate things such as flowers, wool, etc. It can also bleach sugar, straw, paper, etc.

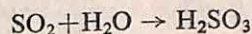
Conversion into sulphur trioxide: SO_2 combines with O_2 in the presence of some catalyst (vanadium pentoxide, V_2O_5 , or platinized asbestos).



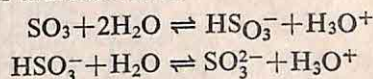
This catalytic oxidation of SO_2 is used in the manufacture of sulphuric acid by the contact process.

- Q. 9.22** (a) SO_2 on reacting with water produces an acid. Name that acid. Comment on the stability of that acid.
- (b) What is the basicity of that acid. How does the aqueous solution of that acid ionize.
- (c) Give the possible reactions of that acid with sodium salt.

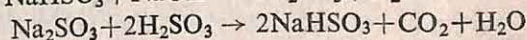
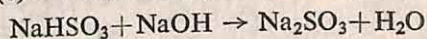
Answer: (a) SO_2 on reacting with water produces sulphurous acid (H_2SO_3). The acid is unstable. It only acts *in situ*. It has never been isolated.



- (b) It is a dibasic acid.



- (c) $\text{NaOH} + \text{SO}_2 \rightarrow \text{NaHSO}_3$

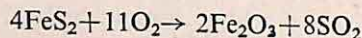
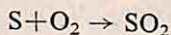


Thus, two series of salts, the sulphites, SO_3^{2-} , and hydrogen sulphites (bisulphites), HSO_3^- , are formed. The latter is found in abundance in dilute solutions.

Q. 9.23 Discuss the contact method for the preparation of sulphuric acid.

Answer: The contact method relies on the conversion of sulphur dioxide to sulphur trioxide in the presence of a catalyst (vanadium pentoxide (V_2O_5) or platinized asbestos). The process involves the following steps.

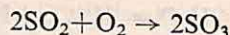
(a) *Manufacture and purification of sulphur dioxide:* Sulphur dioxide is obtained by burning sulphur or by roasting iron pyrites in air.



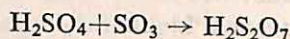
The sulphur dioxide obtained has to be dried, purified and made dust free. Impurities such as arsenic must be removed as these 'poison' the catalyst. The gas, mixed with air, is first passed through an electronic dust precipitator which removes dust particles. It is washed with water in the 'scrubber' chamber and then dried by passing through concentrated sulphuric acid. Finally it is passed through another chamber containing iron (III) oxide to remove arsenic impurity.

(b) *Oxidation of sulphur dioxide to trioxide:* Purified sulphur dioxide (mixed with air) is passed over platinized asbestos or vanadium pentoxide catalyst at 723 K, and sulphur trioxide is formed. The reaction is exothermic and

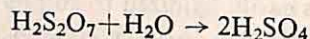
once the process has started, no more heat need to be applied.



(c) *Absorption of sulphur trioxide:* The gases are first passed through a heat exchanger where they are cooled. Sulphur trioxide is then absorbed in concentrated sulphuric acid to give oleum ($H_2S_2O_7$).



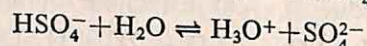
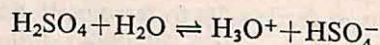
This is then diluted with a calculated amount of water to give sulphuric acid.



Q. 9.24 Describe the properties of sulphuric acid.

Answer: Sulphuric acid is a colourless, oily substance (m.p. 283.5 K, b.p. 593 K). It dissolves in water. During the course of dissolution a large amount of heat is evolved.

Acidic properties: Sulphuric acid is a strong acid in aqueous solutions. It ionizes in two steps.



Thus, it acts as a dibasic acid. Two series of salts ($M^{2+}SO_4^{2-}$ and $M^+HSO_4^-$) are thus possible.

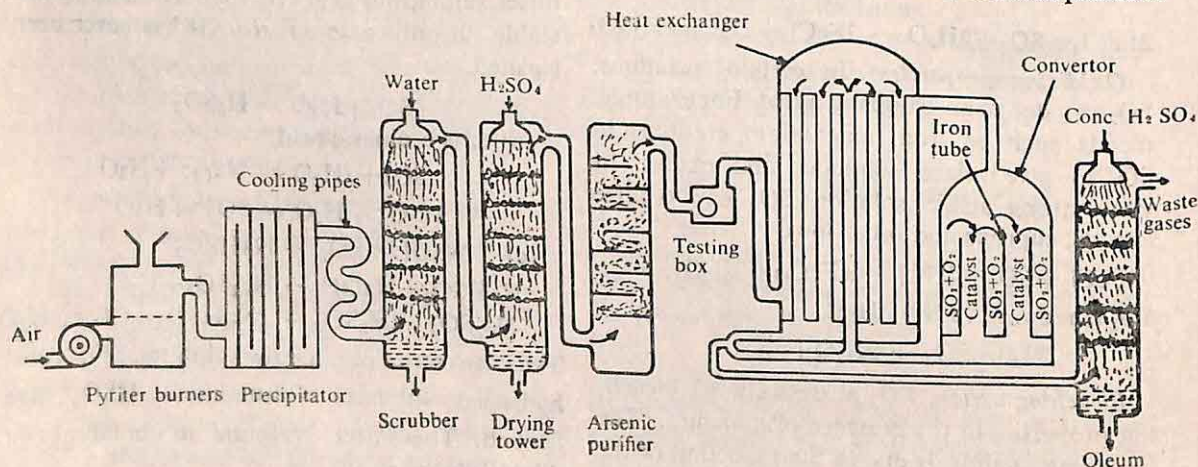
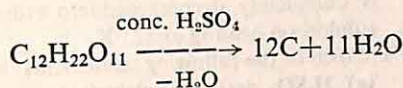


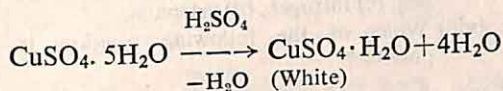
FIG. 9.7 Manufacture of sulphuric acid by the contact method.

Affinity for water: It has a strong affinity for water and thus acts as a dehydrating agent.

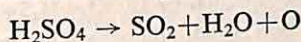
It extracts water from cane sugar and leaves behind a black residual mass.



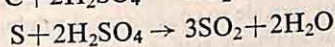
Similarly, crystals of copper sulphate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) loses four of its molecules of water of crystallization in the presence of concentrated sulphuric acid and a white mass is left behind.



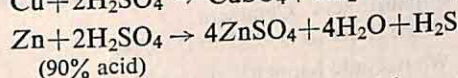
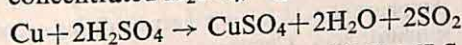
Oxidizing properties: H_2SO_4 acts as an oxidizing agent, particularly when hot and concentrated. This property becomes weak on dilution. Oxidizing action is due to the availability of oxygen atom on decomposition.



- (i) **Action on non-metals:** H_2SO_4 oxidizes carbon and sulphur to their respective oxides.



- (ii) **Action on metals:** Most metals react with concentrated H_2SO_4 , e.g.



- (iii) **Action on salts:** H_2SO_4 reacts with certain salts to form acids, which are more vola-

tile than H_2SO_4 itself. The acids so produced are not oxidized by H_2SO_4 . They are produced by the displacement reaction.



Q. 9.25 List the various uses of H_2SO_4 .
or

Why is sulphuric acid sometimes called 'King of Chemicals'?

Answer: Sulphuric acid is used in various types of industries. The consumption of H_2SO_4 is often regarded as a measure of industrialization of a country. Its main uses are given below:

1. In the manufacture of fertilizers (ammonium sulphate and super phosphate of lime), dyes, explosives (dynamite, TNT, etc.), disinfectants, paints and pigments, plastics, textiles (cotton, wool, and linen fabrics), synthetics fibres, detergents, lacquers, etc.

2. In the production of acids (HCl , HNO_3 , H_3PO_4), etc.

3. In lead accumulators.

4. In the refining of petroleum and its products.

5. As a laboratory reagent, dehydrating and drying agent.

6. In the extraction of certain metals, e.g. copper.

7. For removing oxide layer from the surface of metals before electroplating, galvanizing, etc.

Because of its potential as a laboratory reagent oxidizing agent and dehydrating agent, it is sometimes called 'King of Chemicals'.

EXERCISES

- 9.1 List the elements in group VIA of the periodic table in order of increasing (a) atomic number, (b) melting point, and (c) strength as oxidizing agents.

(Hint: The element with the lowest atomic number is the most oxidizing.)

- 9.2 Give the molecular structure of sulphur in the liquid, solid, and gaseous states.

- 9.3 What happens when sulphur dioxide reacts with:
(a) Aqueous solution of iodine. (b) Aqueous solu-

tion of H_2S . (c) Alkali solution. (d) Aqueous solution of ferric chloride. (e) Colouring material present in flowers. Give chemical equations.

(Hint: Refer to Q. 9.21)

- 9.4 Explain the following:

- Rhombic and monoclinic sulphur behave similarly in chemical reactions.
- Sulphur dioxide is highly soluble in water.
- Sulphurous acid and sulphuric acid behave as dibasic acids.

- (iv) SO_2 is both an oxidizing and a reducing agent.
 (v) While making a dilute solution of sulphuric acid, the acid is added to water instead of water being added to sulphuric acid.
 (vi) Sulphuric acid is called the 'King of Chemicals'.

(Hint: Refer to various questions relating to the properties of sulphur and sulphuric acid.)

- 9.5 (a) Why does concentrated H_2SO_4 decolorize blue colour of copper sulphate crystals. (b) Why do we add conc. H_2SO_4 to water to make a dilute acid sample.
 9.6 Match the statement under column B against the terms/statements under column A.

COLUMN A

- (i) The Frasch process
 (ii) Plastic sulphur
 (iii) Monoclinic sulphur
 (iv) Vanadium pentoxide
 (v) Magnesium oxide
 (vi) Sulphur dioxide

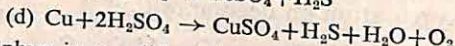
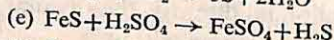
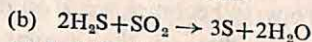
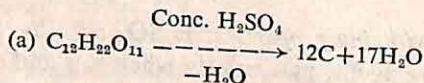
COLUMN B

- (i) an allotrope of sulphur.
 (ii) a catalyst used in the manufacture of H_2SO_4 .
 (iii) Used for the extraction of free sulphur.
 (iv) prepared by melting rhombic sulphur at 370 K.
 (v) used as a bleaching agent.
 (vi) A basic oxide.

- 9.7 Underline the most appropriate answer.

- (i) Which of the following reactions would produce sulphur dioxide?
 (a) Action of hot conc. H_2SO_4 on copper turnings. (b) Action of hot dilute H_2SO_4 on copper turnings. (c) Action of cold dilute H_2SO_4 on copper turnings. (d) Action of hot conc. H_2SO_4 on copper sulphate.
 (ii) Which of the following is wrong? Sulphuric acid can act as (a) an oxidizing agent, (b) a dibasic acid, (c) a reducing agent, (d) a base.
 (iii) Which of the following is wrong? An aqueous solution of sulphur dioxide would (a) turn blue litmus red, (b) turn KMnO_4 solution colourless (c) produce a yellow precipitate with H_2S , (d) turn starch iodide paper blue.
 (iv) Which of the following is used as catalyst in the manufacture of H_2SO_4 : (a) iron oxide, (b) cupric oxide, (c) vanadium pentoxide, (d) phosphorus pentoxide.

- (v) Which of the following statements is wrong about H_2S : (a) H_2S is a stronger acid than water. (b) H_2S is a powerful reducing agent. (c) H_2S is a powerful oxidizing agent. (d) H_2S is completely decomposed into hydrogen and sulphur on heating at 873 K.
 (vi) Which of the following statements is wrong:
 (a) H_2SO_4 acts as a dehydrating agent in its reaction with sugar. (b) Sulphur dioxide acts as a bleaching agent. (c) H_2SO_4 is called the king of chemicals. (d) H_2S gas is not used in qualitative analysis.
 (vii) Ozone is an allotrope of (a) sulphur, (b) oxygen, (c) nitrogen, (d) selenium.
 (viii) Which of the following reactions is not possible?



- 9.8 'Sulphur is a solid and oxygen is a gas'. Explain this statement on the basis of elemental structure of oxygen and sulphur.

(Hint: Refer to Q. 9.2)

- 9.9 Describe one large scale method by which sulphur dioxide can be produced. Outline the conversion of sulphur dioxide to concentrated sulphuric acid. Show that sulphuric acid is

(a) dibasic, and (b) a dehydrating agent.

(Hint: Refer to Q. 9.19, Q. 9.23 and Q. 9.24)

- 9.10 'Sulphurous acid is a stronger oxidizing agent than sulphuric acid'. Comment.

(Hint: Refer to Q. 9.22 to Q. 9.24)

- 9.11 What would happen if the hydrides of oxygen and sulphur are mixed together? How would such a solution behave towards: (a) Wet litmus paper. (b) Concentrated sulphuric acid. (c) Aqueous solution of lead acetate. (d) Aqueous solution of ferrous sulphate. (e) Acidified solution of potassium permanganate.

(Hint: Refer to Q. 9.15)

- 9.12 (a) Which of the two in the following is more polar: (i) H_2O and H_2S , (ii) H_2O and SO_2 . Explain giving reasons.

(Hint: Oxygen is more electronegative than sulphur)

- (b) Discuss the similarities between oxygen and sulphur which justify classifying them in the same group of the periodic table.

(Hint: Refer to Q. 9.1)

Nitrogen and Phosphorus

Both nitrogen and phosphorus belong to group VA of the periodic table (Fig. 10.1).

Nitrogen occurs abundantly in the atmosphere, but it is also present in certain solid nitrate deposits, notably of NaNO_3 . It is obtained from the atmosphere by liquefaction and fractionation. Elemental nitrogen makes up 78% of the atmosphere and nitrogen compounds (especially proteins) are constituents of all living things.

Diagram illustrating the positions of elements N, P, As, Sb, and Bi in the periodic table, showing their relationship to the VA group.

FIG. 10.1

Elemental nitrogen is a colourless and odourless gas which is needed by plants and animals for the life process. It is a typical non-metal. The electron configuration of nitrogen is $1s^2 2s^2 2p^3$ with three of the $2p$ electrons unpaired. It exists as discrete diatomic molecules in the gaseous, liquid and solid states.

Despite its high electronegativity, nitrogen is a relatively unreactive element. The lack of chemical reactivity of nitrogen under ordinary conditions reflects the stability of its molecule and is consistent with a high bond dissociation energy.



However, when heated with certain active metals, nitrogen forms ionic nitrides, e.g. Li_3N , Ca_3N_2 and Mg_3N_2 . At high temperatures nitrogen combines with hydrogen, forming NH_3 , and with oxygen forming NO .

Nitrogen is very essential to all living organisms. For this purpose atmospheric nitrogen is converted into useful organic compounds as it cannot be directly assimilated in the free state. The process of converting free atmospheric nitrogen into its useful compounds is called fixation of nitrogen.

Phosphorus is the most abundant of the elements in the nitrogen family. It ranks tenth among the elements in the earth's crust, 0.12% by weight. It is so active that it is found in nature only in compounds. It is found in phosphate deposits, e.g. fluorapatite $\text{CaF}_2 \cdot 3\text{Ca}_3(\text{PO}_4)_2$, phosphorite $\text{Ca}_3(\text{PO}_4)_2$ or chlorapatite $\text{CaCl}_2 \cdot 3\text{Ca}_3(\text{PO}_4)_2$. Most of the phosphate

minerals are used as fertilizers. Phosphorus is usually extracted from rock phosphate, $\text{Ca}_3(\text{PO}_4)_2$.

Phosphorus is an essential constituent of bones, teeth, muscle, brain and nerve tissues. It is a soft wax-like solid non-metal. Similar to nitrogen it has got five electrons in the outermost shell, with three of the $3p$ electrons unpaired.

Phosphorus has two main allotropes: white (or yellow) phosphorus, and red phosphorus. It contains discrete tetratomic (P_4) molecules in the vapour state. The P_4 molecule exists in solid white phosphorus and in solutions of phosphorus, as well as in phosphorus vapour. In red phosphorus the atoms are bonded together in large aggregates.

In contrast to nitrogen with its slight activity, phosphorus is very active. It burns readily in air forming the pentoxide. Because of the readiness with which it ignites in air, it is stored under water. It reacts vigorously with the halogens to form such compounds as PCl_3 , PCl_5 , PBr_3 and PBr_5 . Concentrated nitric acid oxidizes phosphorus to H_3PO_4 . With alkali, white phosphorus produces phosphine.

Some of the physical characteristics of group VA elements are summarized in Table 10.1. Table 10.2 and 10.3 summarize the chemical properties of nitrogen and phosphorus respectively.

Q. 10.1 Discuss the position of nitrogen and phosphorus in the periodic table.

TABLE 10.1 PHYSICAL CHARACTERISTICS OF GROUP VA ELEMENTS

	Nitrogen	Phosphorus	Arsenic	Antimony	Bismuth
Symbol	N	P	As	Sb	Bi
Atomic number	7	15	33	51	83
Electronic structure	2, 5	2, 8, 5	2, 8, 18, 5	2, 8, 18, 18, 5	2, 8, 18, 32, 18, 5
Physical state	Gas	Solid	Solid	Solid	Solid
Molecular formula	N_2	P_4	As_4	Sb	Bi
Melting point (K)	63.2	86.2	1091	903.5	546
Boiling point (K)	77.2	553.0	—	1653	1743
Density (g/cm^3)	0.879	1.82	5.7	6.6	9.8

TABLE 10.2 CHEMICAL PROPERTIES OF NITROGEN

S. No.	Reaction with	Reaction equation	Comments
1.	Metals : Mg, Ca, Al	$3\text{Mg} + \text{N}_2 \rightarrow \text{Mg}_3\text{N}_2$ $3\text{Ca} + \text{N}_2 \rightarrow \text{Ca}_3\text{N}_2$ $2\text{Al} + \text{N}_2 \rightarrow 2\text{AlN}$	Forms nitrides at high temperatures
2.	Oxygen	$\text{O}_2 + \text{N}_2 \rightarrow 2\text{NO}$	Reaction occurs at very high temperatures (3300 K)
3.	Hydrogen	$3\text{H}_2 + \text{N}_2 \rightarrow 2\text{NH}_3$	Reaction at high pressure at 750 K in the presence of catalyst (Fe)
4.	Halogens	—	Does not react

TABLE 10.3 CHEMICAL PROPERTIES OF PHOSPHORUS

S. No.	Reaction with	Reaction equation	Remarks
1.	Oxygen	$\text{P}_4 + 5\text{O}_2 \rightarrow 2\text{P}_2\text{O}_5$	Burns vigorously in oxygen or air giving white fumes.
2.	Chlorine	$\text{P}_4 + 6\text{Cl}_2 \rightarrow 4\text{PCl}_3$ $\text{PCl}_3 + \text{Cl}_2 (\text{excess}) \rightarrow \text{PCl}_5$	White P_4 ignites spontaneously in Cl_2 .
3.	Acids (a) HNO_3 (b) H_2SO_4	$\text{P}_4 + 20\text{HNO}_3 \rightarrow 4\text{H}_3\text{PO}_4 + 20\text{NO}_2 + 4\text{H}_2\text{O}$ $\text{P}_4 + 10\text{H}_2\text{SO}_4 \rightarrow 4\text{H}_3\text{PO}_4 + 10\text{SO}_2 + 4\text{H}_2\text{O}$	
4.	Alkalies NaOH , KOH	$\text{P}_4 + 3\text{KOH} + 3\text{H}_2\text{O} \rightarrow \text{PH}_3 + 3\text{KH}_2\text{PO}_2$	Reaction on boiling P_4 in conc. solution of alkali. Same with NaOH

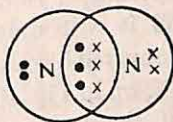
Answer: Both nitrogen and phosphorus belong to group VA of the periodic table. The other elements of the group are arsenic, antimony and bismuth. All these elements possess five electrons in their valence shell. Nitrogen and phosphorus are non-metals. Arsenic and antimony are metalloids. Bismuth is a true metal. The combining power of the group VA elements is commonly three, corresponding to the three electrons deficient from the outermost orbit.

- Q. 10.2** (a) How many electrons are there in the valency shell of nitrogen?
 (b) How many electrons does an atom of nitrogen require to attain the nearest noble gas structure?
 (c) Give the electron dot structure of diatomic nitrogen molecule.
 (d) What is the nature and number of bonds in diatomic nitrogen molecule.

Answer: (a) There are 5 electrons in the valency shell of nitrogen.

(b) An atom of nitrogen requires 3 electrons to attain the nearest noble gas structure.

(c) The electron dot structure of diatomic nitrogen molecule is



(d) There are three covalent bonds in diatomic nitrogen molecule.

Q. 10.3 Discuss the structure of phosphorus molecule.

Answer: At room temperature phosphorus exists as tetratomic phosphorus molecule P_4 . These four atoms occupy four corners of a regular tetrahedron. Each phosphorus atom is bonded to three other atoms by single covalent bonds (see Fig. 10.10, p. 87)

Q. 10.4 Give reasons for the following.

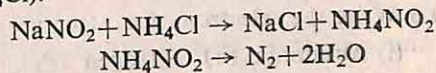
- (a) Nitrogen and phosphorus are insoluble in water.
 (b) Nitrogen is a gas while phosphorus is a solid at room temperature.

Answer (a) The bonds in nitrogen and phosphorus molecules are covalent, i.e. they are non-polar substances. Water is a polar solvent. Therefore, they are insoluble in water.

(b) Nitrogen exists as a diatomic molecule while phosphorus exists as a tetratomic molecule at room temperature. The molecular weight of nitrogen is $2 \times 14 = 28$ amu while that of phosphorus is $4 \times 31 = 124$ amu. Nitrogen exists as a gas due to its low molecular weight, while phosphorus exists as a solid due to its high molecular weight.

Q. 10.5 Describe the laboratory method for the preparation of nitrogen. State its physical and chemical properties.

Answer: In the laboratory, nitrogen is produced by heating an equimolecular solution of sodium nitrite ($NaNO_2$) and ammonium chloride (NH_4Cl).



The apparatus used is shown in Fig. 10.2. Nitrogen gas is collected over water.

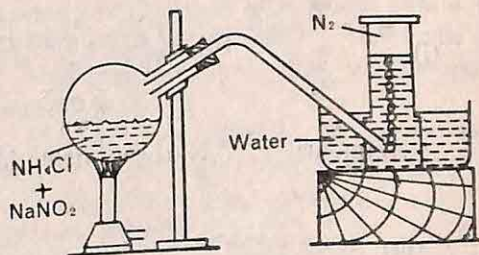


FIG. 10.2 Preparation of nitrogen.

PHYSICAL PROPERTIES

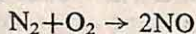
Nitrogen is a colourless, odourless gas. It is lighter than air and slightly soluble in water. It

is neither combustible nor a supporter of combustion. Its melting point is 63.2 K and boiling point is 77.2 K. It has a density of 0.879 g/cm³.

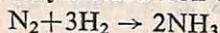
CHEMICAL PROPERTIES

Nitrogen is very stable and relatively inert. It does not react with acids, alkalis, etc. It reacts with some elements and compounds but only under conditions of high temperature and pressure.

(a) *Reaction with oxygen:* Nitrogen combines with oxygen at 3300 K to form nitric oxide. Such high temperatures can be produced by electric sparks.

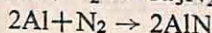
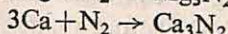
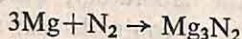


(b) *Reaction with hydrogen:* The reaction takes place at 750 K under high pressure in the presence of finely divided iron catalyst.



(c) *Reaction with halogens:* Nitrogen does not react with halogens.

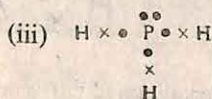
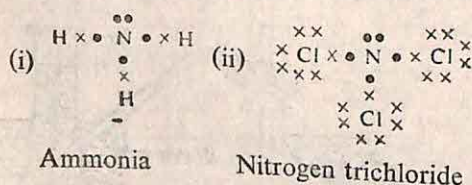
(d) *Reaction with metals:* At high temperatures some metals such as calcium, magnesium and lithium react with nitrogen to form nitrides.



Q. 10.6 Write the electron dot structures of:

- (i) Ammonia (ii) Nitrogen trichloride
(iii) Phosphine.

Answer:

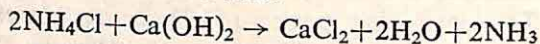


Phosphine

Q. 10.7 (a) How is ammonia prepared in the laboratory?

- (b) Describe an experiment to show in the laboratory that ammonia gas is very soluble in water and the solution formed is basic.

Answer: (a) Ammonia is prepared in the laboratory by heating a mixture of ammonium chloride with slaked lime.



The gas is collected by the downward displacement of air (Fig. 10.3).

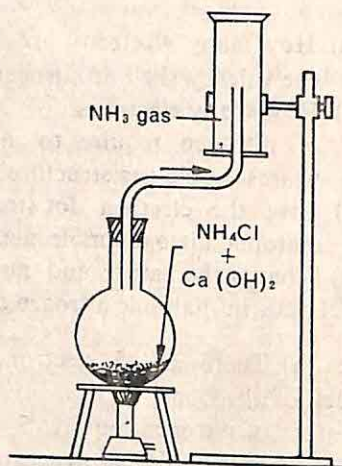


FIG. 10.3 Preparation of ammonia.

(b) *Fountain experiment:* Take a round-bottomed flask and fill it with ammonia gas. Take water containing some red litmus in a beaker. Set the apparatus as shown in Fig. 10.4. On pressing the rubber teat of the dropper, water gets into the flask and dissolves the ammonia gas. It creates a low pressure in the flask and the coloured solution rises up through the jet and forms a fountain in the flask. The red colour of the solution changes to blue. This shows that ammonia gas is highly soluble in water and its solution is basic in nature.

Q. 10.8 Discuss the physical and chemical properties of ammonia.

Answer: Ammonia is a colourless gas having a pungent smell. It is lighter than air and is

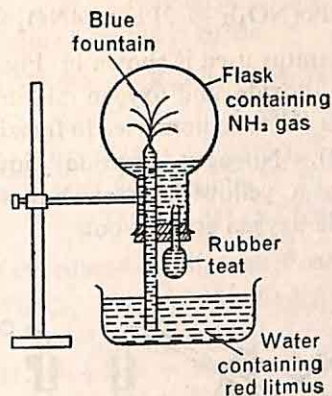
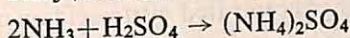
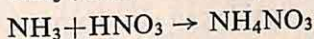
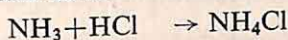


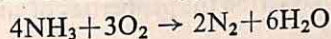
FIG. 10.4 The fountain experiment.

very soluble in water. It can easily be liquefied to a colourless liquid with a boiling point of 240 K.

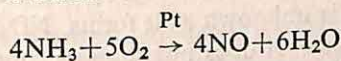
(a) *Reaction with acids* : Ammonia neutralizes acids to form salts.



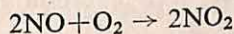
(b) *Reaction with oxygen* : Ammonia burns in the presence of excess oxygen to give nitrogen.



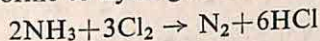
In the presence of red hot platinum (catalyst) ammonia is oxidized to nitric oxide gas.



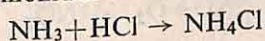
The nitric oxide immediately combines with oxygen to give brown coloured nitrogen dioxide gas.



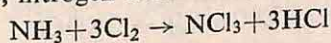
(c) *Reaction with chlorine*: First nitrogen reduces chlorine to hydrogen chloride.



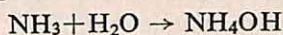
The hydrogen chloride thus formed combines with excess of ammonia producing dense white fumes of ammonium chloride.



If excess of chlorine is used, a highly explosive substance, nitrogen trichloride, is formed.



(d) *Reaction with water* : Ammonia dissolves in water to give ammonium hydroxide.

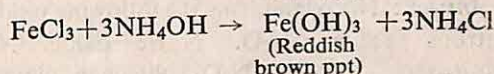
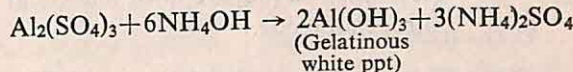


Ammonium hydroxide behaves as an alkali.

(e) *Complex formation*: On adding ammonia solution to salt solutions of metals such as Cu, Zn, Ag, complex compounds are formed.

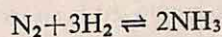


(f) *Formation of hydroxides* : With solutions of salts of some metals, ammonium hydroxide causes precipitation of hydroxides of the metals.



Q. 10.9 How is ammonia manufactured?

Answer : Ammonia is manufactured by the Haber's process. It involves the direct combination of nitrogen and hydrogen under pressure in the presence of finely divided iron catalyst at 773K. The reaction is reversible and exothermic



Q. 10.10 State the uses of ammonia and its compounds.

Answer : (i) Salts of ammonia such as ammonium sulphate and ammonium nitrate are extensively used as fertilizers. Ammonia is used in the manufacture of urea, an important nitrogenous fertilizer.

(ii) In the manufacture of nitric acid (Ostwald's process) and other compounds like sodium carbonate (Solvay's process).

(iii) As a refrigerant.

(iv) In the production of polyamide plastics and many organic chemicals.

(v) In the manufacture of artificial silk (rayon).

(vi) As a grease remover.

(vii) In household detergents.

(viii) As a non-aqueous solvent.

(ix) Alkali metal ammonia solution is used for reduction in organic reactions.

(x) NH_4Cl is used as an electrolyte in dry cells and Leclanche cells. It is also used for preparing digestive medicines and for tinning utensils.

(xi) NH_4NO_3 is used widely in making explosives. It is used in the manufacture of calcium ammonium nitrate (CAN), a fertilizer.

(xii) $(\text{NH}_4)_2\text{CO}_3$ is used in baking powders and as one of the ingredients of inhaling salts.

Q. 10.11 Name the various oxides of nitrogen. How will you prepare nitric oxide and nitrogen dioxide.

Answer : Nitrogen forms the following oxides: Nitrous oxide, N_2O . Nitric oxide, NO . Dinitrogen trioxide, N_2O_3 . Nitrogen dioxide, NO_2 or dinitrogen tetroxide, N_2O_4 . Dinitrogen pentoxide, N_2O_5 .

Nitric oxide, NO : It is usually prepared by the action of cold dilute nitric acid on copper turnings.

$3\text{Cu} + 8\text{HNO}_3 \rightarrow 3\text{Cu}(\text{NO}_3)_2 + 4\text{H}_2\text{O} + 2\text{NO}$
The apparatus employed is shown in Fig. 10.5. The gas is collected over water.

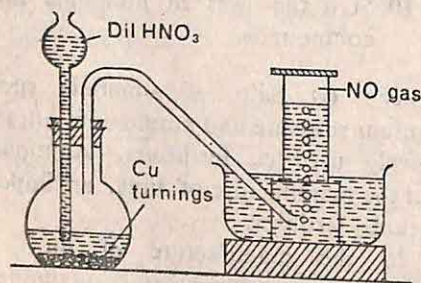
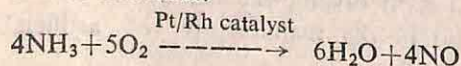
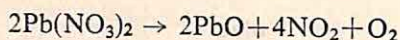


FIG. 10.5 Preparation of nitric oxide.

On a large scale it is obtained by the catalytic oxidation of ammonia.



Nitrogen dioxide, NO_2 : It is usually obtained in the laboratory by heating lead nitrate.



The apparatus used is shown in Fig. 10.6. The nitrogen dioxide and oxygen mixture is passed through a 'U' tube immersed in freezing mixture (ice + salt). Nitrogen dioxide liquefies and collects as a yellowish green liquid in the 'U' tube while oxygen escapes out.

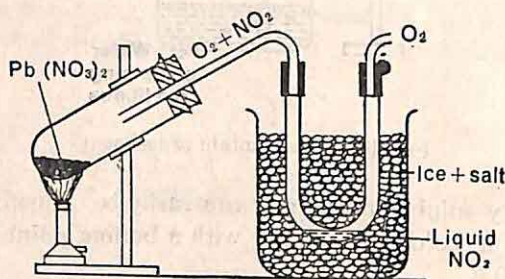
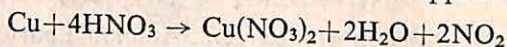


FIG. 10.6 Preparation of nitrogen dioxide.

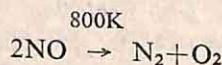
Nitrogen dioxide can also be produced by the action of concentrated nitric acid on copper.



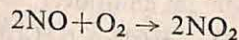
Q. 10.12 Describe the properties of nitric oxide.

Answer : Nitric oxide is a colourless gas, heavier than air. It is slightly soluble in water. Its smell is unknown as it forms NO_2 on contact with air. It does not support combustion.

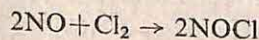
Thermal stability : Nitric oxide is thermally the most stable oxide of nitrogen. Above 800 K there is slight decomposition to oxygen and nitrogen.



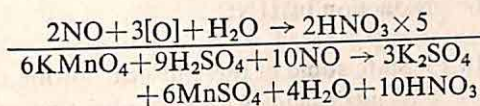
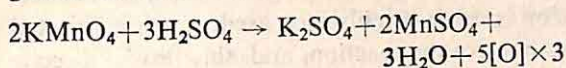
Reaction with oxygen : On coming into contact with air or oxygen it immediately gives reddish brown fumes of nitrogen dioxide.



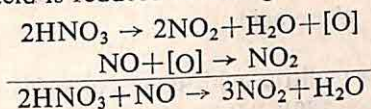
Reaction with chlorine : It readily combines with chlorine to form nitrosyl chloride.



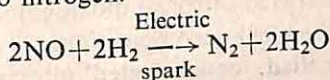
Reducing agent: Acidified potassium permanganate is reduced by nitric oxide.



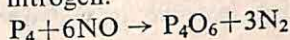
Nitric acid is reduced to nitrogen dioxide.



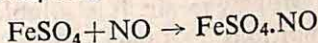
Reaction with hydrogen: Nitric oxide is reduced to nitrogen.



Reaction with phosphorus: Nitric oxide is reduced to nitrogen.



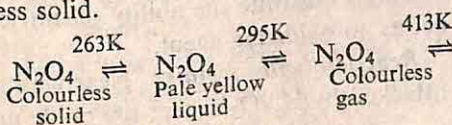
Reaction with ferrous sulphate: Nitric oxide dissolves in ferrous sulphate to give a dark brown solution containing a complex compound $\text{FeSO}_4 \cdot \text{NO}$



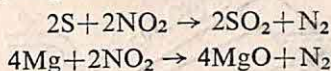
Q. 10.13 Discuss the properties of nitrogen dioxide.

Answer: Nitrogen dioxide is a reddish brown poisonous gas with a pungent smell. It is heavier than air and dissolves in water to produce a mixture of nitric and nitrous acids.

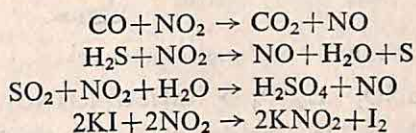
Effect of temperature: Above 413K nitrogen dioxide has a reddish brown colour and a density corresponding to the formula NO_2 . On cooling below 413K the colour almost entirely disappears and the density corresponds to N_2O_4 . On cooling below 295K (the boiling point of N_2O_4), it liquefies to a pale yellow liquid with a melting point of 263K. Below 263K, N_2O_4 is a colourless solid.



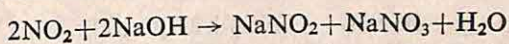
Combustion: Though nitrogen dioxide does not burn itself, it supports the combustion of sulphur, magnesium, etc.



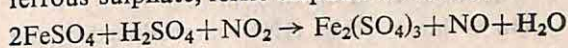
Oxidizing properties: Nitrogen dioxide oxidizes carbon monoxide, hydrogen sulphide, sulphur dioxide, potassium iodide, etc.



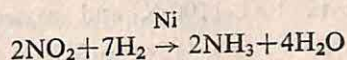
Reaction with alkalis: It neutralizes alkalis to form salts.



Reaction with ferrous sulphate: On passing nitrogen dioxide through a solution of acidified ferrous sulphate, ferric sulphate is formed.



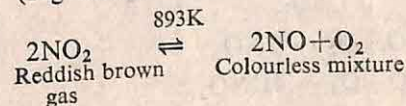
Reaction with hydrogen: In the presence of finely divided nickel catalyst, nitrogen dioxide is reduced to ammonia.



Q. 10.14 Name some oxyacids of nitrogen? Which is the most important oxyacid? How is it prepared in the laboratory? How is it manufactured on a large scale?

Answer: The oxyacids of nitrogen are nitric acid (HNO_3), nitrous acid (HNO_2) hyponitrous acid ($\text{H}_2\text{N}_2\text{O}_2$) and pernitric acid (HNO_4). Nitric acid is the most important oxyacid.

HNO_3 is prepared in the laboratory by gently heating a mixture of sodium (or potassium) nitrate and concentrated sulphuric acid in a retort. The brownish vapours of the acid produced are condensed in a cooled receiver (Fig. 10.7).



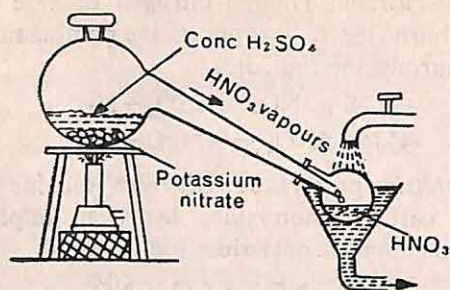
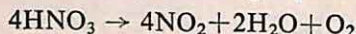


FIG. 10.7 Preparation of nitric acid.



The nitric acid is often decomposed by the heat of reaction and the nitrogen dioxide formed dissolves in the acid, colouring it yellow :



This is why gentle heating is necessary.

The acid is generally purified by distillation or by passing carbon dioxide through it.

On a large scale, HNO_3 is produced by the catalytic oxidation of ammonia (Ostwald's process, Fig. 10.8). Dry ammonia gas mixed with excess air (1 : 10 by volume) is heated under pressure to 1000-1100 K and passed rapidly

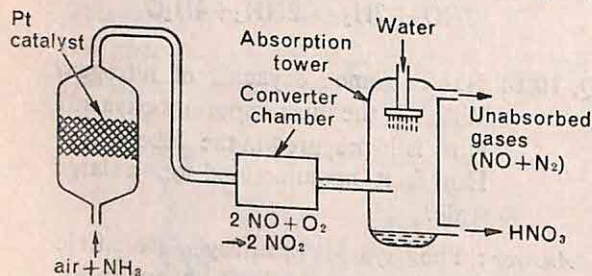
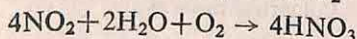
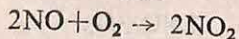
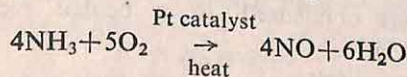


FIG. 10.8 Manufacture of nitric acid.

over a platinum gauze catalyst, to obtain nitric oxide. The oxide is oxidized by air to NO_2 in the converter chamber. NO_2 is then absorbed in water to give HNO_3 .



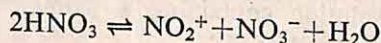
A 90% conversion of the feed is achieved. By substituting pure oxygen for air, the conversion rate is highly increased; steam is injected to control the reaction, and this leads directly to the production of HNO_3 .

Q. 10.15 State some of the physical properties of nitric acid. Also give a brief account of some of the chemical reactions of nitric acid.

Answer : Nitric acid is a colourless liquid boiling at 359K. It freezes to a white solid at 231K. Concentrated nitric acid is often yellow due to dissolved nitrogen dioxide produced by its photochemical decomposition.

The so called 'concentrated' nitric acid used in the laboratory contains about 30% water and the true anhydrous acid has markedly different properties (for instance it will not react with copper).

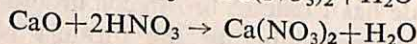
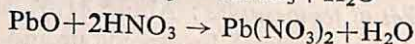
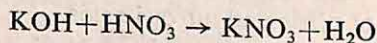
It undergoes self-dissociation to a small extent.



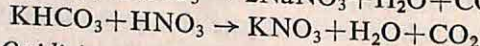
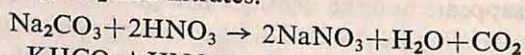
It fumes strongly in air. It is soluble in water in all proportions and the solution has a sour taste and turns blue litmus red. It corrodes the skin strongly.

Acidic properties : Nitric acid is strong and stable in aqueous solutions.

It reacts with alkalis and basic oxides forming nitrates.



It reacts with carbonates and bicarbonates giving CO_2 and nitrates.

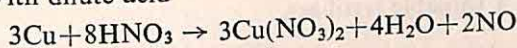


Oxidizing properties : The following types of reactions illustrate the ability of nitric acid to act as an oxidizing agent.

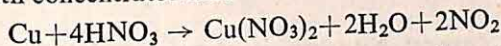
Reaction with metals : Nearly all metals are attacked by HNO_3 except the noble metals (Au,

Pt, etc). Its reaction with many metals is slowed down because it renders the surface passive. Aluminium is not attacked to any significant extent while Fe and Cr are made passive by the acid. The reaction products formed depend upon the concentration of the acid, the activity of the metal and the temperature.

The reactions of nitric acid with copper are:
With dilute acid

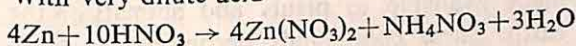


With concentrated acid

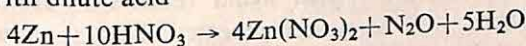


The reactions of active metals, such as Zn with HNO_3 are:

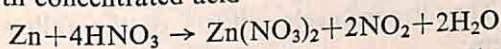
With very dilute acid



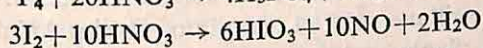
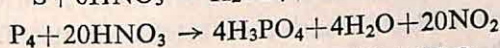
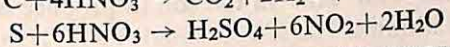
With dilute acid



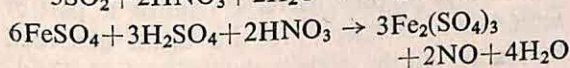
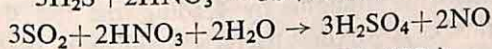
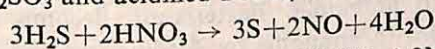
With concentrated acid



Reaction with non-metals: Sulphur, carbon, iodine, and phosphorus are oxidized by concentrated nitric acid to their oxyacids (or acid anhydrides) and NO_2 is formed.



Reaction with inorganic compounds: Concentrated nitric acid and even dilute nitric acid oxidizes some compounds such as H_2S to S, SO_2 to H_2SO_3 and acidified FeSO_4 to $\text{Fe}_2(\text{SO}_4)_3$.



- Q. 10.16** (a) State the uses of nitric acid.
(b) Comment on the following statements:
(i) Nitric acid lying in a bottle appears yellow.

(ii) Copper reacts in different ways with nitric acid.

(iii) In the laboratory preparation of HNO_3 , low temperature is used.

Answer: (a) Nitric acid is used in various types of industries.

Chiefly it is used as given below:

1. In the manufacture of fertilizers (ammonium nitrate and calcium ammonium nitrate), explosives (dynamite, TNT, picric acid, gun cotton), dyes, plastics, drugs, perfumes, textile (cotton, wool, and linen) synthetic fibres, photographic films.

2. In the purification of certain metals, e.g. Ag and Au.

3. In the manufacture of artificial silk and cellulose nitrate.

4. In the extraction of certain metals.

5. In the preparation of chemicals, e.g. phosphoric acid from phosphorus and oxalic acid from carbohydrates.

6. As a laboratory reagent.

7. For etching designs or names upon metals like copper, brass and bronze.

(b) (i) (ii) Refer to Q. 10.15

(iii) Refer to Q. 10.14.

Q. 10.17 Describe the uses of nitrogen and its compounds.

Answer: Nitrogen: (1) The important applications of nitrogen are based upon its inactivity.

(i) For creating inert atmosphere in chemical processes.

(ii) To prevent the oxidation of easily oxidizable substances through exposure to air.

(iii) In industries for handling of gasoline and other inflammable liquids.

(iv) In mercury thermometers for filling the space above mercury and thus reducing the evaporation of mercury, and for providing an inert atmosphere in electric bulbs.

(v) In the packing of foods: canned foods such as coffee and hydrogenated vegetable

oils retain their flavour and colour much better if packed in nitrogen instead of air.

2. Elemental nitrogen is used in various processes for 'fixing' atmospheric nitrogen.

3. In the manufacture of nitrolime, ammonia and nitric acid.

Compounds: The uses of ammonia and nitric acid have already been discussed. (Refer to Q. 10.10 and Q. 10.16.)

Q. 10.18 (a) What is meant by 'fixation of nitrogen'.

(b) Describe in brief various methods of fixation of nitrogen.

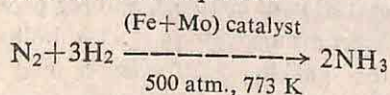
Answer: (a) The process of converting atmospheric nitrogen into useful nitrogenous compounds is called 'fixation of nitrogen'.

(b) There are two methods of fixation of nitrogen: (i) Natural method (ii) Artificial method.

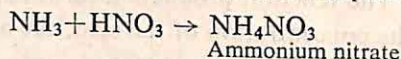
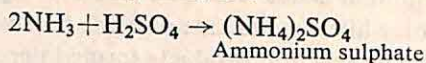
Natural method: Atmospheric nitrogen and oxygen combine during lightning to form nitric oxide. This immediately gets oxidized to nitrogen dioxide. The nitrogen dioxide dissolves in rain-water producing nitric acid, which further reacts with the salts present in the soil forming nitrites and nitrates. These nitrogenous compounds help in the growth of plants.

Some soluble nitrogen compounds are made available for plant growth when decay of plant and animal remains takes place. Some algae, fungi and mosses can also convert free atmospheric nitrogen into soluble nitrogen compounds, which are used up by plants. Some micro-organisms present in the roots of leguminous plants (pea, groundnut, beans, etc.) convert atmospheric nitrogen into compounds of nitrogen. These compounds are assimilated by the soil.

Artificial method: Nitrogen is converted into ammonia by Haber's process



Ammonia so produced is converted into nitrogenous fertilizers, e.g. ammonium sulphate, ammonium nitrate, urea, etc.



Ammonia can also be converted to nitric acid and to calcium ammonium nitrate (CAN), which is a valuable fertilizer.

Q. 10.19 What is the nitrogen cycle in nature?

Answer: Nitrogen is very essential for the growth of plants and animals. Atmospheric nitrogen in the form of nitrogenous compounds is made available to plants and animals on the earth. These compounds decompose to form free nitrogen which again reaches the atmosphere, and the cycle is repeated. This is known as 'nitrogen cycle'.

The nitrogen cycle consists of the following steps:

(i) During lightning, atmospheric nitrogen and oxygen combine to form nitric oxide. This with oxygen produces nitrogen dioxide which with rain water forms nitric acid. Nitric acid reacts with salts in the soil to produce nitrites and nitrates.

(ii) Plants absorb these soluble nitrates from the soil and convert them into protein. Animals eat plants and the protein is digested by them. In the body, a part of the protein is used to form flesh, and the rest is excreted as urea in urine which is decomposed by bacteria in the soil to ammonia. Bacteria also decompose the proteins to ammonia by feeding on the dead animals. Nitrifying bacteria oxidize a part of ammonia to nitrates which are again absorbed by plants and the cycle is thus continued. Denitrifying bacteria oxidize the rest of ammonia to nitrogen which goes back to the atmosphere.

(iii) Some leguminous plants like bean, pea, etc. have little nodules in their roots. These nodules contain nitrogen fixing bacteria called

'symbiotic bacteria'. These bacteria convert atmospheric nitrogen to proteins. The rest of the processes are the same as described above.

(iv) The action of denitrifying bacteria on nitrogen compounds in the soil results in the direct release of N_2 to the atmosphere.

The various processes involved in the nitrogen cycle are portrayed in Fig. 10.9.

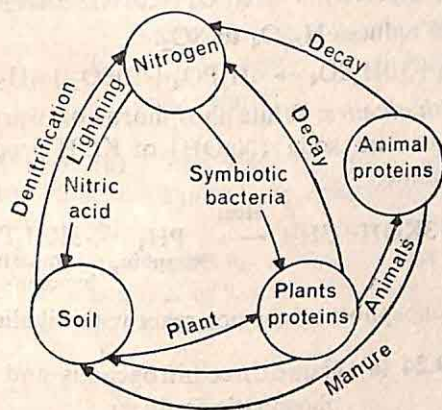
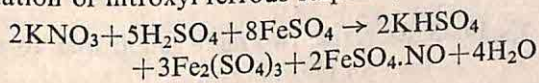


FIG. 10.9 The nitrogen cycle.

Q.10.20 Describe the test for nitrate ions.

Answer: The solution of the salt being tested is taken in a test tube, and freshly prepared ferrous sulphate solution is added to it. Concentrated sulphuric acid is then very gently poured down the sides of the test tube. Being heavy, sulphuric acid forms a separate layer at the bottom. If a dark brown ring is formed at the junction of the acid and the solution, the presence of nitrate ion in the solution is confirmed. The dark brown ring is due to the formation of nitroxyl ferrous sulphate, $FeSO_4 \cdot NO$



Q. 10.21 Describe the various allotropes of phosphorus.

Answer: Phosphorus exists in several allotropic forms of which only two are of general

interest and importance. These are white or yellow phosphorus and red phosphorus. White phosphorus exists as P_4 molecules (Fig. 10.10). Red phosphorus is a polymer with P_4 molecules linked to each other.

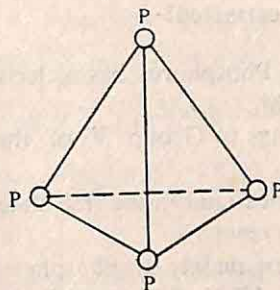


FIG. 10.10 P_4 molecules of white phosphorus.

White phosphorus is a white waxy solid which becomes yellow on exposure to light. It has a garlic like smell. It is insoluble in water but very soluble in carbon disulphide (CS_2) and less so in ether, chloroform and other organic solvents. It melts at 317.7K and boils at 553.3K. It is highly poisonous in nature and is very reactive.

In contact with air, white phosphorus glows with a greenish light. This phenomenon is known as phosphorescence. It catches fire spontaneously in air (303K). Due to this it is stored under water.

White phosphorus can be converted to red phosphorus by heating it at 510K in an inert atmosphere.

Red phosphorus is a purple-red amorphous powder, insoluble in both water and carbon disulphide. It is not poisonous and is much less reactive than white phosphorus. It has no smell. It is safe to handle as it does not burn spontaneously in air. Its ignition temperature is very high.

Red phosphorus can be converted to white phosphorus by heating it in an inert atmosphere until it vaporizes, and then condensing the vapour.

- Q. 10.22** (i) How many electrons does phosphorus have in its outermost orbit? (ii) To which group in the periodic table does it belong? (iii) Why is it not found in the free state in nature? (iv) How does it occur in nature? (v) How is phosphorus extracted?

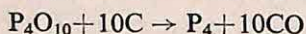
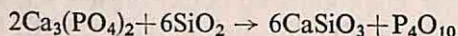
Answer: (i) Phosphorus has 5 electrons in its outermost orbit.

(ii) It belongs to Group V of the periodic table.

(iii) It is not found in the free state in nature as it is highly reactive.

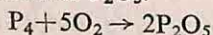
(iv) It occurs mainly as phosphates such as fluorapatite $[\text{CaF}_2 \cdot 3\text{Ca}_3(\text{PO}_4)_2]$, phosphorite $[\text{Ca}_3(\text{PO}_4)_2]$ or chlorapatite $[\text{CaCl}_2 \cdot 3\text{Ca}_3(\text{PO}_4)_2]$. It is an essential constituent of bones, teeth, muscle, brain and nerve tissues.

(v) Phosphorus is usually extracted from rock phosphate $[\text{Ca}_3(\text{PO}_4)_2]$ by mixing it with silica sand and crushed coke and heating it in an electric furnace.



- Q. 10.23** Give some of the important reactions of phosphorus.

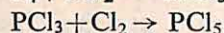
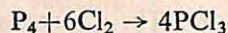
Answer: *With oxygen:* The most important property of phosphorus is its chemical activity towards oxygen. Because of its low ignition temperature, it catches fire in oxygen (or air) giving white fumes of P_2O_5 .



White phosphorus glows in the dark (phosphorescence). This is because some of its vapours are oxidized by atmospheric oxygen with the emission of light.

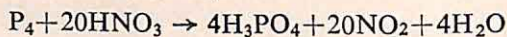
Red phosphorus burns to give P_2O_5 only when heated above 533 K.

With chlorine: Phosphorus combines with the halogens exothermally. White phosphorus ignites spontaneously in chlorine to form tri- and pentachlorides.

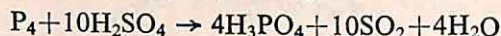


Red phosphorus also reacts with Cl_2 forming tri- and pentachlorides but only at high temperatures.

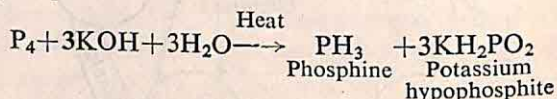
With acids: White phosphorus reduces conc. HNO_3 to NO_2 . Phosphorus is oxidized to phosphoric acid (H_3PO_4).



It also reduces H_2SO_4 to SO_2 .



With alkalis: White phosphorus on warming with caustic soda (NaOH) or KOH produces phosphine.



Red phosphorus does not react with alkalis.

- Q. 10.24** (a) Name three nitrogenous and one phosphatic fertilizer.
(b) Name two nitrogenous explosives and two nitrogen compounds used as laboratory reagents.
(c) Name one phosphorus compound used for killing rats.

Answer: (a) The three nitrogenous fertilizers are: (i) Ammonium sulphate (ii) Urea (iii) Calcium ammonium nitrate (CAN). Phosphatic fertilizer is calcium superphosphate.

(b) The two nitrogenous explosives are: (i) Nitroglycerine (ii) Trinitrotoluene (TNT).

The two nitrogen compounds used as laboratory reagents are: (i) Ammonium hydroxide (ii) Nitric acid.

(c) Zinc phosphide is used for killing rats.

- Q. 10.25** (a) Name two main allotropic forms of phosphorus.
(b) Which allotropic form is insoluble in both water and carbon disulphide and which allotropic form is soluble in carbon disulphide and insoluble in water.

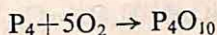
Answer: (a) The two main allotropic forms of phosphorus are: (i) White or yellow phosphorus (ii) Red phosphorus.

(b) Red phosphorus is insoluble in both water and carbon disulphide and white or yellow phosphorus is soluble in carbon disulphide and insoluble in water.

- Q. 10.26** (a) How will you convert white phosphorus into red phosphorus?
(b) Why is white phosphorus kept under water?

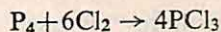
Answer: (a) When white phosphorus is heated to 523 K in an inert atmosphere it changes to red phosphorus.

(b) White phosphorus is kept under water because when it is exposed to air it gets oxidized to tetraphosphorus decaoxide.

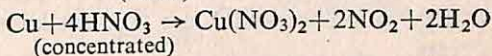
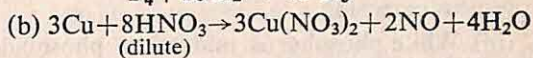
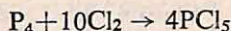


- Q. 10.27** With the help of chemical equations, describe the reactions between:
(a) Phosphorus and chlorine.
(b) Nitric acid and copper.
(c) Calcium phosphate and concentrated sulphuric acid.
(d) Sodium nitrate and concentrated sulphuric acid.

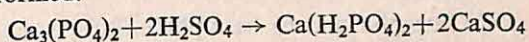
Answer: (a) White phosphorus forms phosphorus trichloride with chlorine.



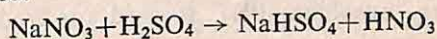
Red phosphorus also forms the trichloride. With excess of chlorine, phosphorus pentachloride is formed.



(c) When calcium phosphate is digested with concentrated sulphuric acid, superphosphate is formed.



(d) When sodium nitrate is heated with concentrated sulphuric acid, nitric acid is formed.



- Q. 10.28** Compare the physical and chemical properties of white and red phosphorus.

Answer: The physical and chemical properties of red and white phosphorus are compared in Table 10.4.

- Q. 10.29** Give some important uses of phosphorus and its compounds.

TABLE 10.4 PHYSICAL AND CHEMICAL PROPERTIES OF RED AND WHITE PHOSPHORUS

S. No.	Property	White phosphorus	Red phosphorus
1.	State and colour	White waxy solid	Purple-red amorphous powder
2.	Smell	Garlic-like	No smell
3.	Poisonous nature	Very poisonous	Not poisonous
4.	Solubility	Insoluble in water, soluble in organic solvents	Insoluble in water and organic solvents
5.	Ignition	Ignites at 303K. Burns spontaneously in air	Ignites at 530K
6.	Phosphorescence	Greenish glow	No phosphorescence
7.	Reaction with Cl_2	Ignites spontaneously giving PCl_3 and PCl_5	Reacts on heating forming PCl_3 and PCl_5
8.	Reaction with alkalis	Produces PH_3 on heating	No reaction